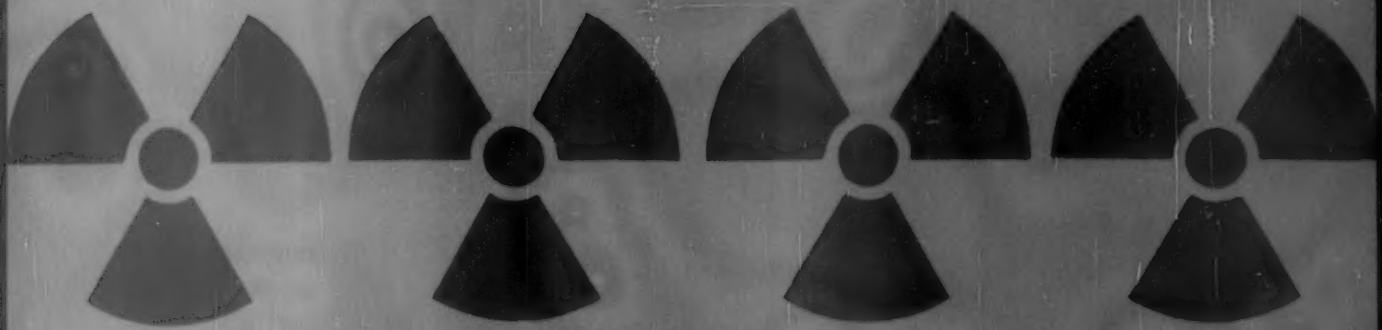
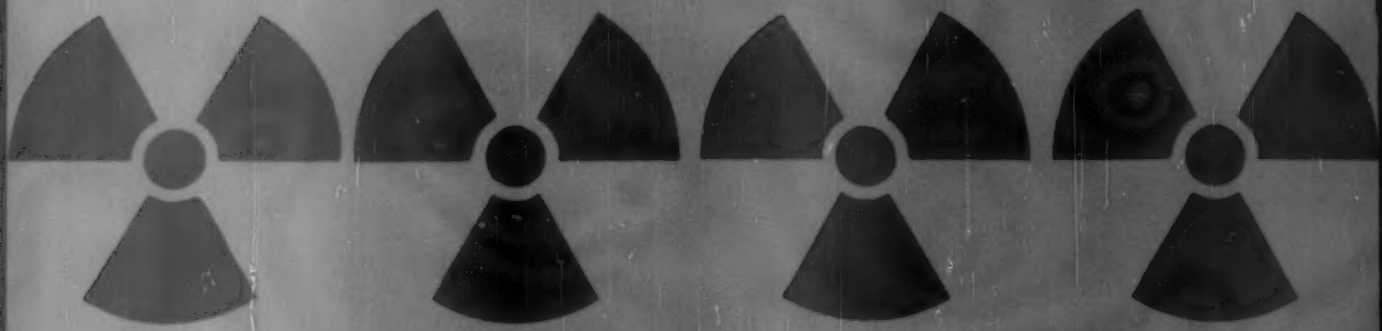
JUNE 1961

NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING



HEALTH PHYSICS SOCIETY in Las Vegas, June 11-16



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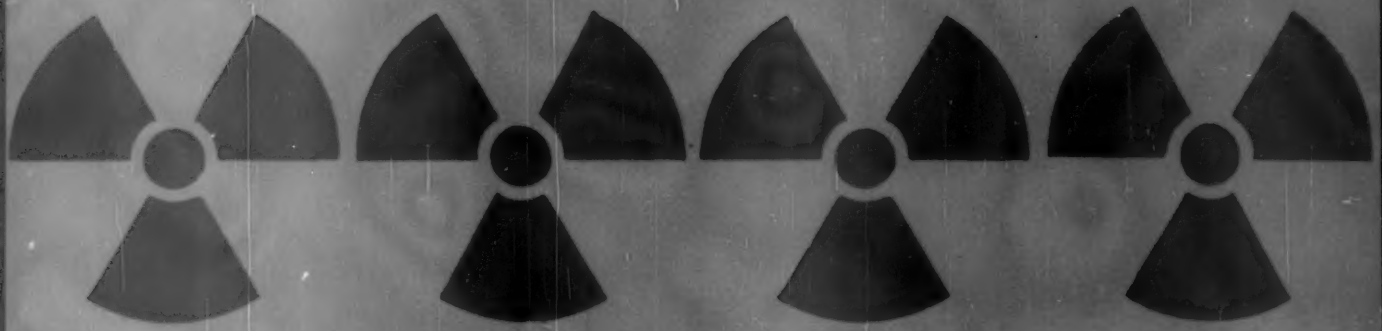

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X-RAYING LARGEST STAINLESS STEEL "HOT" PUMP CASTING

Above, technicians mark segment of casting for one of many hundreds of X-ray pictures employing a 24,000,000 volt Betatron at the Bonney Floyd Foundry. *Below*, X-ray picture is carefully inspected for flaws.

Shown here is the largest single-piece stainless steel pump casting built today. The X-ray procedure is just one of the many inspections necessary to assure the high quality in Worthington nuclear pumps. Special designs were necessary to allow a single casting to be made for this size pump.

A more complete discussion of special equipment criteria and manufacturing techniques for nuclear requirements is available in a Worthington pamphlet, "Manufacturing For a Nuclear Power Plant." Ask for RP-1092.

To provide the special attention required to engineer and manufacture nuclear products, Worthington has an Advanced Products Division which specializes in pumps and other equipment for nuclear plants. For further information, write Worthington Corporation, Nuclear Department 106-7, Harrison, New Jersey.

WORTHINGTON

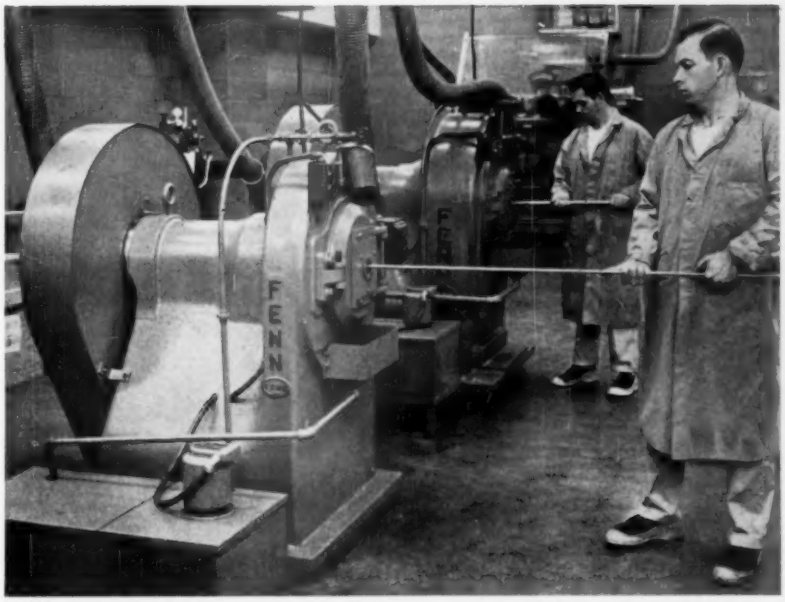
PRODUCTS THAT WORK FOR YOUR PROFIT

New B&W Method of Fabrication Promises Longer Core Life

Advanced swaging technique provides higher power output per unit of core volume, improved operating characteristics, longer fuel life.

Babcock & Wilcox is now putting into production a radically new method of fuel element fabrication which promises significant cost savings throughout the reactor lifetime. In this new technique, powdered uranium dioxide is vibrated into thin tubes which are then reduced by swaging to the final diameter. During the swaging process the powdered fuel is compressed to high density, resulting in more intimate and uniform contact between the tube wall and the fuel particles.

Because of their greater uniformity, lower costs, shorter and more predictable fabrication time, the new elements represent an important step toward more economical atomic power.



Operators feed loaded fuel rods into swaging machines at the B&W Nuclear Facilities Plant.

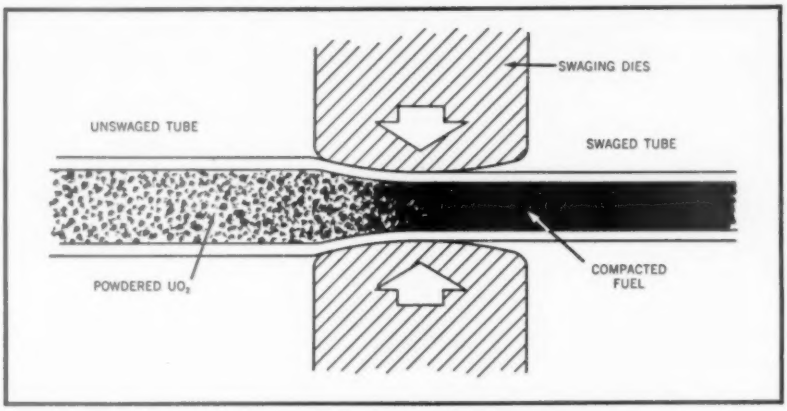
HIGHER POWER OR SMALLER SIZE

Swaged fuel elements reduce the internal resistance to heat flow. Indications are that they can develop higher power than a pellet-type core of the same size – or, can provide equal power from a smaller core.

REDUCED FABRICATION COST

Swaging eliminates all pellet pressing, grinding, and sintering, resulting in substantially lower fabrication costs. It is readily adaptable to loading operations which will be required in the future when handling reprocessed fuels.

For further information on this new fuel element design, contact The Babcock & Wilcox Company, 161 East 42nd Street, New York 17, New York.



Cross section diagram showing the B&W swaging method of fuel rod fabrication.

NC-116

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NUCLEAR POWER APPLICATIONS

Vol. 19, No. 6 - June, 1961

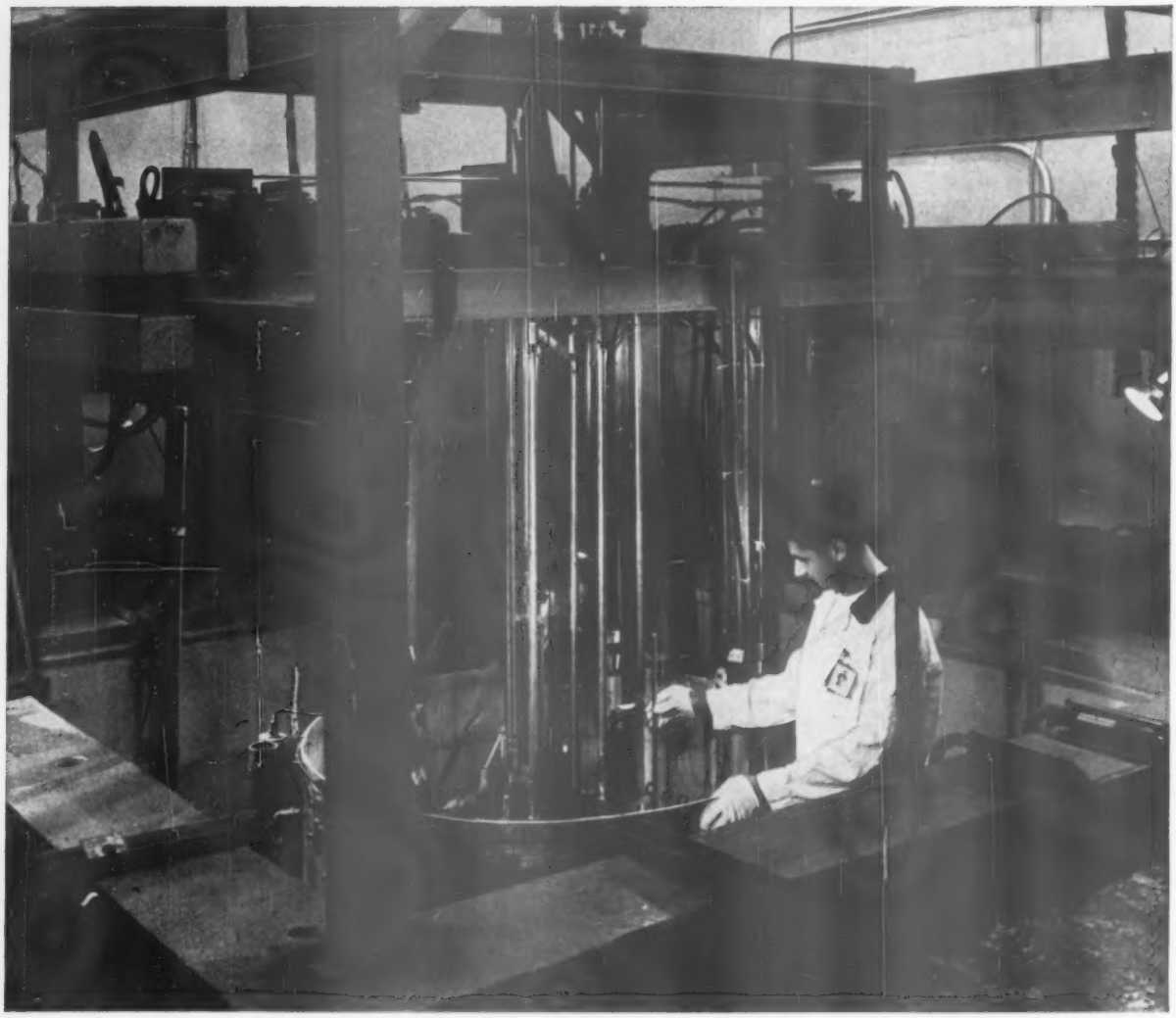

Photo courtesy of The Martin Company

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...about NUCLEONICS

The Function of an Editor

One of our favorite preoccupations is the nature and purpose of NUCLEONICS. When we spend long hours talking to writers and readers about what we are and what we ought to be, we find that among the questions that come up most often is, "Why do you edit the material I send you?"

To serve the reader. The basic purpose of NUCLEONICS is to serve the reader. We are somewhat different, therefore, from a society journal, founded and managed as an outlet for the publications of society members. From the difference comes our need for editors and many of the problems they are asked to face.

Who is a NUCLEONICS editor? If he is a news man, he came to us with a background in journalism and a curiosity about things nuclear. By constant communication with technical editors and the engineers and scientists of the field he has acquired significant technical knowledge. The technical editor, on the other hand, is a person who has come to the staff with scientific or engineering background and then learned NUCLEONICS writing. All of our technical editors have technical degrees (the average is about two degrees per editor) and various amounts of technical experience in industrial and university jobs.

What does he do? He solicits, reviews, edits and writes the material that makes the magazine. He solicits because we want to make sure that our coverage of the nuclear field is complete and balanced. If we take only what comes over the transom, our coverage is likely to develop by accident and at random. Solicitation fills the gaps.

As a reviewer the editor represents the NUCLEONICS reader. He reads an article critically, looking for parts that the reader will not want to read (he knows them already) and for sections that the reader will find inadequate. (If the editor doesn't understand it as it is presented, he feels that the reader won't either.) After the review he sends the author his suggestions for additions, deletions and revisions.

Editing means making the manuscript into an article. At the minimum this means writing headlines and cross heads, banks and figure captions that fit our type sizes. It includes decisions about figure sizes and how to redraw them so that labels and line thicknesses will be readable and attractive. At the maximum, editing can mean a complete rewriting job, combining several sources of information and grafting in the additions that bring a story up to date.

The editor's dilemma. The job is fun, but it isn't all poems and sweetness. On the one hand the editor must make the reader happy. The product is for him. On the other, he must be the author's friend; for the author makes the product. How does an editor meet the situation when the author objects?

Often the hardest part of the job is telling an author how we want to change his manuscript. No author likes to hear that his writing can be improved. No one wants to take the time to revise and rewrite something he finds satisfactory as he wrote it the first time. So we often face the difficulty that serving the reader requires saying things an author doesn't want to hear. But it is part of the job. We hope that as a NUCLEONICS reader you appreciate the effort—and that when you are a NUCLEONICS author you do too.

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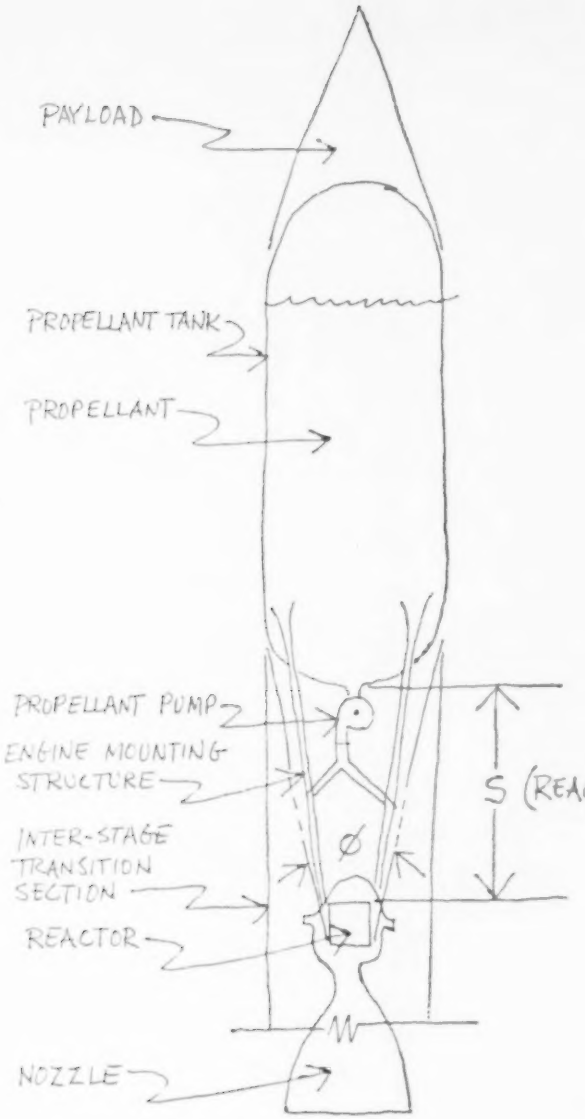
COMING FEATURES

Components for Nuclear Reactors (July)

Irradiated Polyethylene

Beta-Excited X-Rays

Nuclear Navy (September)


PAYLOAD
PROPELLANT TANK
PROPELLANT
PROPELLANT PUMP
ENGINE MOUNTING STRUCTURE
INTER-STAGE TRANSITION SECTION
REACTOR
NOZZLE
S (REACTOR-TANK SEPARATION DISTANCE)
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INTER-STAGE TRANSITION SECTION WEIGHT = fS
INTEGRATION OF THESE FACTORS WILL LEAD TO AN OPTIMUM S.

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- REACTOR DESIGN
- PROPULSION REACTOR START-UP
- NUCLEAR ROCKET SAFETY ANALYSIS
- RADIATION EFFECTS ON ROCKET SYSTEM
- FUEL ELEMENT DEVELOPMENT
- VEHICLE DESIGN
- CRYOGENICS

THE PROBLEM OF RADIATION HEATING IN NUCLEAR-POWERED ROCKETS

Martin liquid hydrogen test facility at Denver where heat transfer experiments are carried out.

The first flight of a U.S. nuclear rocket is targeted for the mid 1960's; but the achievement of this objective will depend upon the successful solution of many complex technical problems. At Martin, we are investigating all the areas listed above in a coordinated program designed to help solve these problems. An example of one approach to a problem area is illustrated. It concerns the propellant temperature elevation and excessive evaporation that might result from intense radiation created by the reactor.

Martin engineers at Baltimore and Denver are working on several approaches to the solution of this problem: 1) separation between the reactor and the propellant; 2) continuous cooling of certain components by the cryogenic propellant; and 3) shadow-shielding of propellant and components. Optimum solution appears to involve a combination of these alternatives, and can have a substantial influence on overall rocket system weight and performance.

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NUCLEAR REACTIONS

About Weinberg's Article

DEAR SIR:

This letter is a commentary on the article by Dr. Alvin Weinberg, Director, Oak Ridge National Laboratory on book publishing in the nuclear field that appeared in the May issue of NUCLEONICS.

We subscribe wholeheartedly to Dr. Weinberg's continuing plea for the need for the development of a scholarly tradition in nuclear energy. It is certainly paramount for anyone striving to achieve this tradition to be an avid reader of the best literature available in his chosen field. There is no better way to benefit from the teachings and experiences of authors in the various disciplines. For the reading of the book literature to be of any benefit, it is obviously important that books be of the highest quality that can be achieved. Certainly, the literature in any field should not be any less scholarly than the research done in that particular field.

The nuclear field, unfortunately, has suffered in its book literature from several things. First, as Dr. Weinberg points out, the glamour surrounding the nuclear energy field and, also, the newness of the field have caused many authors and many publishers to want to rush into print too quickly with books.

But what is probably a much more important force in producing the flood of nuclear books has been the policies of the Atomic Energy Commission. In the earlier years of the nuclear energy field, when secrecy was a hindrance to communication of information and when there was a great deal of pressure on the AEC from the Congress to disseminate nuclear information, there was justification for AEC to sponsor a number of nuclear books.

In recent years, however, the need for a vast publishing program by the AEC has been reduced and has probably even disappeared. Despite this, AEC has had underway in the past several years—and has underway currently—what is probably one of the largest book publishing programs in the world. AEC is making an effort to publish books on every conceivable facet of the nuclear energy field, whether a particular facet is of broad interest or of a very specialized interest.

In the process of developing this massive publishing program, AEC has by the use of many lures and pressures been able to take into its stable the bulk of competent technical people who might serve as book authors.

AEC does not have as a consideration in its book publishing activities the question of a minimum market for any book it wants to publish. Such a minimum market is not necessary when you are operating on a subsidy basis.

Commercial book publishers, on the other hand, need very much to be concerned with whether any particular

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book venture they undertake will be of a sufficient quantity and of sufficient interest to bring the requisite minimum sale. Simple publishing economics force publishers to pay the utmost attention to the quality of both the authors and manuscripts they select. Of course, there are times when mistakes are made. But these are honest mistakes and should not be looked at as evidence of the fact, as Dr. Weinberg points out, there is no "incentive for excellence."

We would strongly suggest to Dr. Weinberg that, rather than throw his barbs at commercial publishers, he would do the concept of the scholarly tradition in the nuclear energy field a better service if he were to scrutinize the publishing policies, procedures and objectives of the AEC and make such recommendations to the AEC as he deems desirable to assure that the Commission's activities will serve the scientific community in the best way possible.

—KENNETH ZEIGLER
Editor-in-chief
College Department
McGraw-Hill Book Co.
New York 36, N. Y.

Electrical Excitation in the U. S.

DEAR SIR:

The use of electrical excitation for chemical processing in place of ionizing radiation, as discussed by Westermark, (NU, May, 1961, p. 90), has not escaped the recent attention of American investigators.

Lemmon et al., *Science* **129**, 1740 (1959), found that simple electrical discharge could so augment the Wilzbach labeling techniques that the effect could be almost entirely ascribed to the electrical discharge [also see NU, Aug., 1960, p. 102—ed.].

Other recent work has indicated that electrically accelerated tritium or C^{14} ions can be used for labeling. I have noted that electrical discharges in mixtures of C^{14} oxides and organic gaseous compounds give an array of C^{14}-labeled products. The commercial possibilities of such reactions are of potential interest since the power would possibly be cheaper than nuclear power. Westermark's article calls our attention to these possibilities, timely now because of greater insight in the mechanism of ionizing-radiation chemical effects.

—BERT M. TOLBERT
Associate Professor
University of Colorado
Boulder, Colorado

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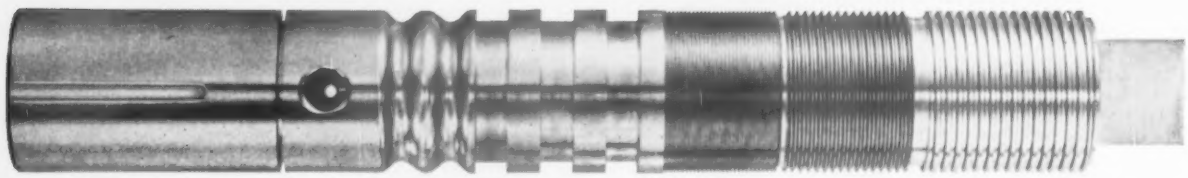

This shaft was turned. It was key-slotted, drilled, tapped and shouldered. It was threaded, milled, grooved and chamfered. It was step-bored, with three inside diameters. Who could plate a piece like this all over—inside and out—and expect a uniform coating?

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Indicative of our nuclear work past and present are these projects

- Core component for Plum Brook test reactor, NASA
- A1W core support components for reactor, Westinghouse
- A1W and D1G shipping and installation container for reactor and reactor cores, Westinghouse and GE-KAPL
- ECGR pressure vessels and core components, H.K. Ferguson
- Containment vessel and loading face shield for Hallam reactor, Atomics International
- Fuel handling vehicle for Enrico Fermi reactor, Power Reactor Development Company
- Thermal shield components for GE-Hanford Laboratory reactor, General Electric
- HTGR reactor vessel and components, General Atomics
- D1G, D2G components for shipboard reactor servicing, General Electric-KAPL
- Magnet cores for Brookhaven, Cambridge, Penn-Princeton and Argonne National laboratories

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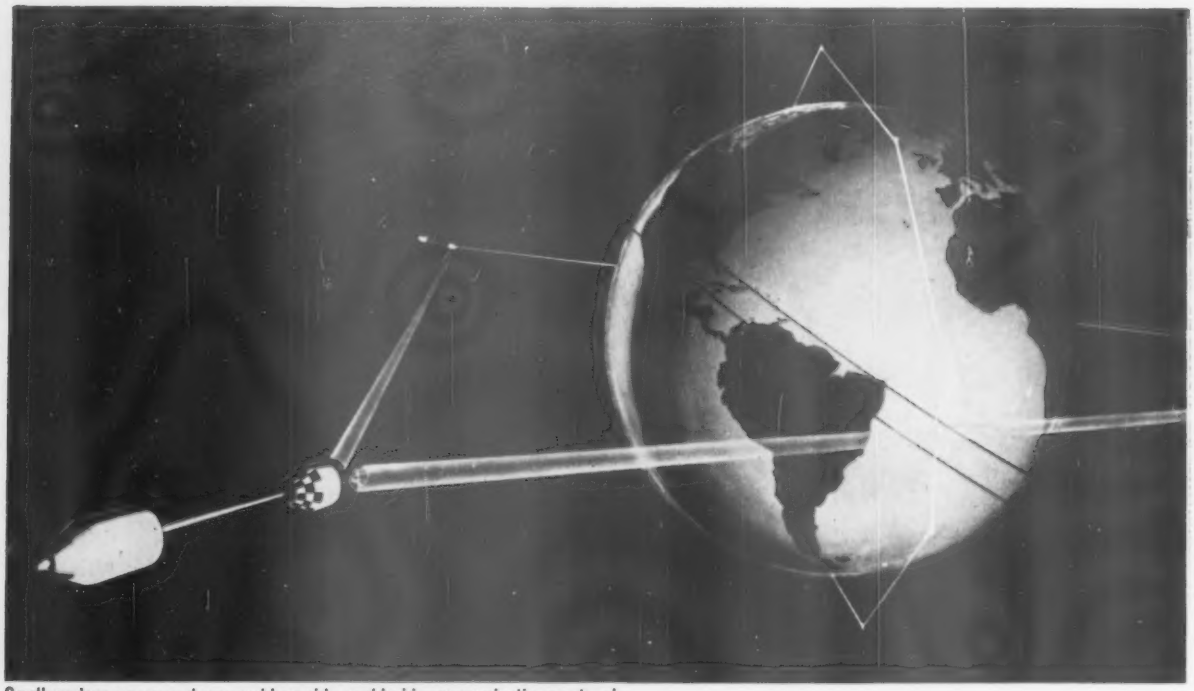

Small nuclear power systems could provide world-wide communications network.

NUCLEAR POWER IN ORBIT

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HEAT TRANSFER. Senior engineer to be responsible for system engineering studies on the thermal, hydraulic and thermodynamic performance of compact power reactor systems.

For specific details write: Mr. C. F. Newton, Personnel Office, Atomics International, 8900 DeSoto Avenue, Canoga Park, Calif.

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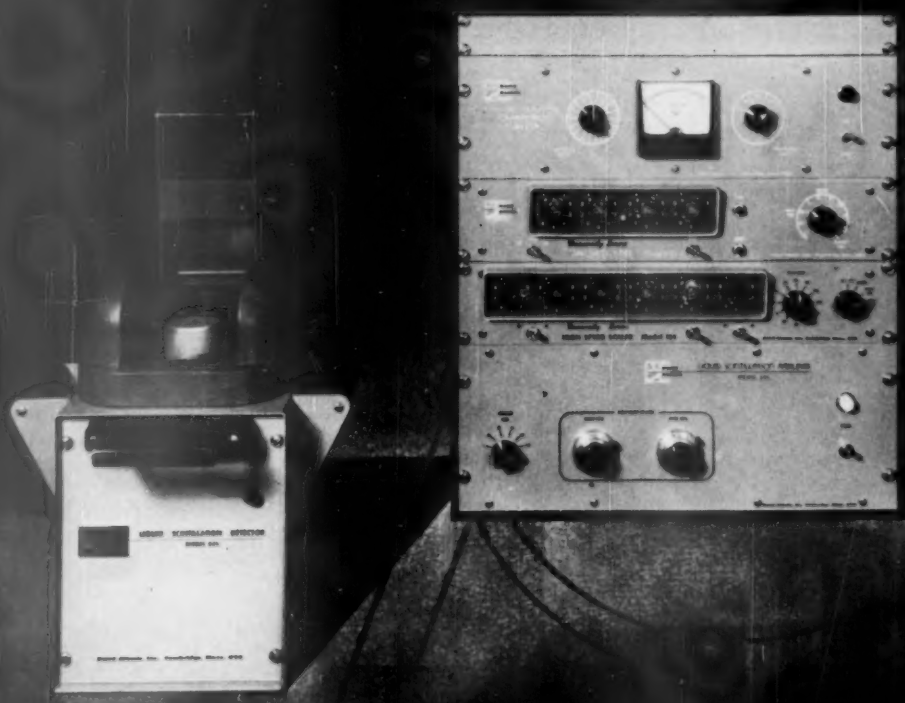

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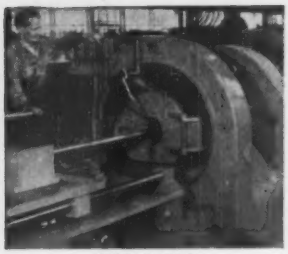
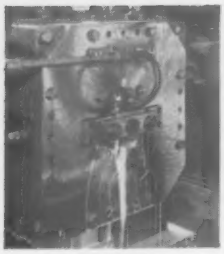
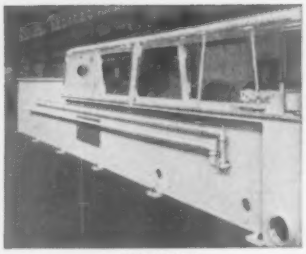


SWAGING MACHINES



TURKS HEADS



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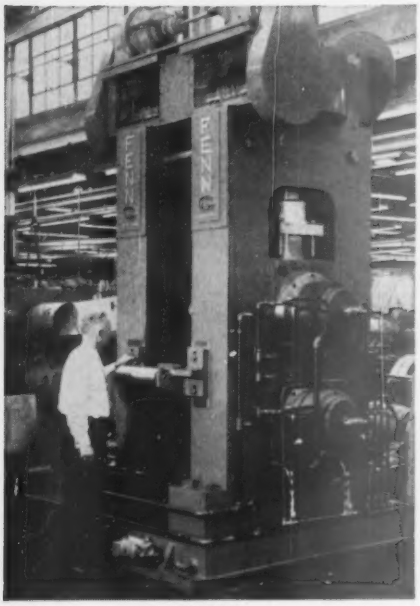
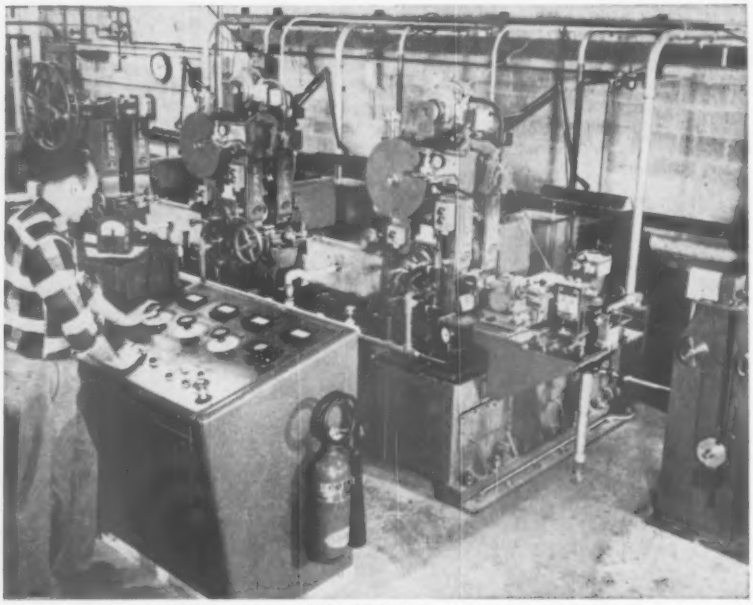


ROLLING MILLS



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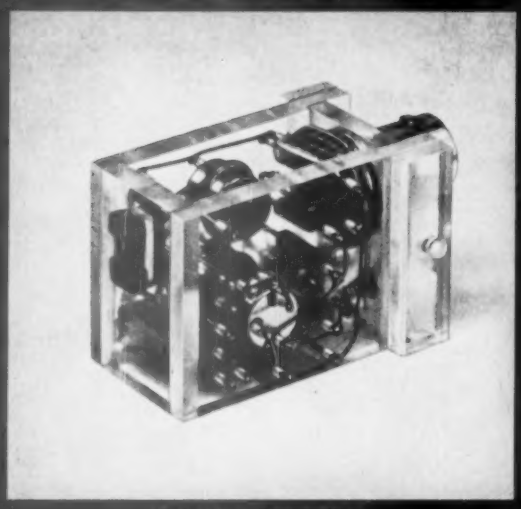

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The Sciaky Electron Gun produces specific beam density previously possible only with accelerating potential higher than 100,000 volts. The Sciaky gun, entirely contained within the atmosphere of the welding chamber, will operate in any angular position. *Both* gun and fixture can be moved to any position within the chamber while welding.

Figure 1

Advanced focusing design results in electron beam welds of 12 to 1 depth to width characteristics. Figure 1 shows a deep penetrating butt weld in type 304 stainless steel. Plate thickness is .5". Note lack of heat-affected zone.

GUN AN INDUSTRIAL TOOL

The gun construction is simple and rugged. Precise alignment is inherent in design, and is not dependent upon assembly adjustments. If necessary, filaments can be easily and quickly replaced in less than five minutes. As shown in Figure 2, the Sciaky Electron Beam Gun is small and

Figure 2

compact. A simple spacer arrangement optimizes gun optical system throughout a wide range of output power without compromise of specific beam energy. As a result, the

Figure 3

Sciaky gun is optimized at current ranges of 250, 150, 100 and 50 MA. at 30,000 volts. Output power is continuously adjustable within each range.

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Low voltage (30,000 v. maximum) and highly refined chamber design eliminate x-ray hazards to operator, which are a severe problem with higher voltage equipment. As a result, the Sciaky low voltage system needs no costly shielding, even when welding at highest output.

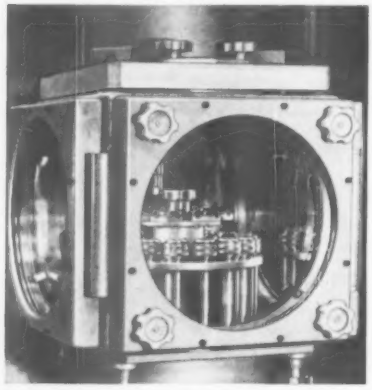

Figure 4

As shown in Figures 3 and 4, complete accessibility and visibility are provided by this latest Sciaky design. All sequence controls of the dial feed unit (Figure 4) are fully automatic. This production unit is being used to weld end-caps to tubes.

Regardless of your specific area of interest, you'll find the Sciaky combination of welding experience and electron beam technology is well advanced. Sciaky is Exclusive Licensee under Stohr, U.S. Patent 2,932,720.

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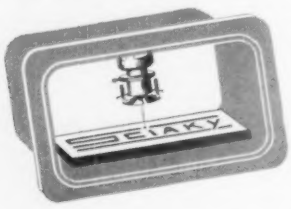

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PLUTONIUM FUEL PROGRAM

Newly completed NDA Facility to develop PU-U-Carbide fuel elements

NDA has just completed installation of a new Plutonium Handling Facility at its Pawling Laboratories to carry out a prime contract for plutonium-uranium-carbide fuel development as part of the AEC's Fuel Cycle Development Program.

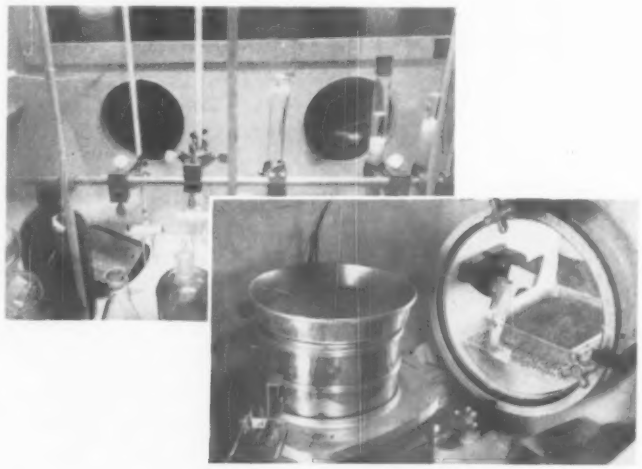
The objective is to develop fuel elements capable of producing economically attractive nuclear power at the earliest feasible time. Plutonium has important potential but its fuel characteristics must be documented through research and development, such as that now going on at NDA. Current efforts encompass a wide variety of investigations, ranging from fuel element conceptual design and fabrication through fuel irradiation and evaluation, and irradiated fuel reprocessing.

This plutonium fuel program is but one example of the many challenging projects now going forward at NDA, utilizing a skilled team of scientists, engineers, technicians and supporting personnel at the company headquarters in White Plains and at its Pawling Laboratories.

It takes the experience of many years and many people to achieve the valuable goal of utility through application of advanced technology. For a truly professional approach to research, development and application, look to NDA, where tomorrow's advances are being worked on today.

Current and prospective contracts at NDA involving the AEC, NASA, the Departments of the Army, Navy and Air Force, and private industry, provide a healthy growth climate and career opportunities for qualified scientists and engineers. Apply a professional approach to your career — research these opportunities for you at NDA. Write in confidence to Director, Professional Personnel.

Project engineer at one of glove boxes where actual work with plutonium is performed. Facility contains an interconnected series of metallurgical boxes, a series of chemistry boxes, hoods and other equipment for packaging, handling, air and inert gas circulation.



Interior view of one of the chemical boxes (above), and one of the metallurgical boxes, showing interconnecting passageway. All boxes and hoods are under negative pressure with inert gas atmosphere.

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NUCLEONICS NEWS OF THE MONTH

AEC, JCAE, Industry Determined to Move on Power Reactors

Seaborg Takes Firm Stand on Bolstering Program Next Year; Holifield Asks More Vigorous Approach; Forum Begins Study

The push is on for stepping up the nation's power reactor program next year.

From all sides—from AEC, the Joint Committee on Atomic Energy, and industry—came word last month that fresh and purposeful studies will be carried out over the next few months to determine what needs to be done to get nuclear power off dead center.

1. AEC. In his first policy statement on nuclear power, new AEC Chairman Glenn T. Seaborg came out clearly and boldly for (a) "moving ahead" on the projects already authorized but stalled; (b) possibly offering additional incentives to industry; (c) if that proves inadequate, possibly going to a program of government construction. He thus gave the first sign, in testimony on AEC's authorization bill, before JCAE's subcommittee on legislation, that the Administration is prepared, and preparing, to act to relieve the current softness in the reactor industry, and pledged that ways will be found to meet the U. S. objective of economic nuclear power by 1968.

New Editorial Feature: Reflecting the accelerating developments in nuclear energy in space, we introduce on page 28 a new department: Space Nucleonics

2. JCAE. Chairman Chet Holifield also called—in a speech before the American Public Power Association—for a new and greater effort on nuclear power. He said the "partnership" approach between government and industry had been tried and found wanting, and that stronger leadership by the U. S. was needed.

3. Forum study. A new Atomic Industrial Forum group—the Ad Hoc Committee on National Policy—got to work on a several-months' study of the nation's energy sources and where nuclear energy fits into this resource picture. Chairman is Chauncey Starr, president of Atomics International. It is likely that the committee this fall will propose a more vigorous approach toward the achievement of competitive nuclear power.

Seaborg's Stand

Admitting candidly that "during the past two years our experience in the cooperative prototype power demonstration program has been disappointing," Seaborg declared that "We are interested in seeing these projects go forward." He cited the 50-Mwe organic reactor, which AEC is now offering to publicly-owned utilities (*see p. 24*) after privately-owned utilities had passed it over; the 50-Mwe improved-cycle boiling water and the 20-Mwe pressurized water reactor, both of which encountered siting problems.

For the latter two he said AEC had new expressions of interest from publicly-owned utilities, to supplant proposals that have been withdrawn. On the organic reactor, Seaborg said AEC expects to begin construction early in 1962, "unless our experimental work encounters unforeseen difficulties." He also declared AEC would shortly issue an invitation to process industries to cooperate on building the low-temperature process heat reactor, which earlier had been reported as being dropped.

New incentives. "Experience indicates," Seaborg told the subcommittee, "that it may be necessary to consider modifying our present ground rules to assure construction of additional prototypes necessary to make continued progress . . . The staff has been studying various types of incentives such as a capital grant, operating subsidy, modification of prices and charges for nuclear materials, fast tax write-off and financing of long transmission lines. As yet, we have not reached a conclusion . . . We will expand our studies and discuss the problem with members of the nuclear industry and with this Committee. If we determine that financial incentives can give us the program we need to move ahead toward our national objective, we will make appropriate proposals to the Congress as part of our FY-1963 authorization request."

Government program. "However," the AEC chief went on, if this does not suffice, "it might even be necessary to consider the possibly more expensive approach of a program under which the Government would construct and initially operate those pro-

Reactor projects: three up, Florida down

Three stalled reactor projects from the AEC 1960 building program seemed to get new life last month—but another in the joint AEC-industry program withered on the vine. AEC is negotiating with Wolverine Electric Co-Op on the 20-Mwe Small Pressurized Water Reactor (formerly SSPWR) and with Dairyland Power Co-Op on the 50-Mwe Improved-Cycle Boiling Water Reactor. Wolverine had proposed a 10-Mwe Foster Wheeler homogeneous reactor in the second round demonstration program in 1956; Dairyland had been a bidder on the SSPWR. Allis-Chalmers was AEC's final choice to build ICBWR, American Standard to build SPWR, on the first go-around last year. AEC also asked for new expressions of interest in an experimental low-temperature process-heat reactor (*see p. 26*) . . . However, AEC terminated the Florida West Coast project to build a 50-Mwe heavy-water-moderated, gas-cooled reactor, because of "technical and economic uncertainties." The project had been reoriented several times, and a new reorientation had been proposed (NU, April '61, 29). Two Florida utilities, with 14 utilities in East Central Nuclear Group, had been working on this project, with General Nuclear Engineering Corp. as nuclear design agent.

totype plants which are needed to reach our goals. Under this approach, the Commission, using fixed-price competitive bidding among private contractors, would construct complete plants on publicly- or privately-owned utility power grids; the utility would operate the plant and buy electric power from the plant for a fixed period at some predetermined rate developed under competitive proposals from utilities. At the end of the fixed period, the utility would be committed by contract to purchase, and the government to sell, the plant at a price which would allow it to compete with conventional plants of the same size."

Finally, the chairman pledged continuance of AEC's long-range program, "seeking major advances or possible breakthroughs through laboratory work, and through construction and operation of reactor experiments. . . . I am hopeful that considerably more significant cost reductions will ultimately result from such longer-range programs as the development of reactor systems having high conversion ratios, breeding potential, or long-lived, high-burnup fuels, or systems capable of utilizing the thorium–U-233 or plutonium cycles, or taking advantage of thermionic conversion. Further, we will move ahead on . . . reactors which may have broader uses than electric power generation . . . such things as the LAMPRE [Los Alamos Molten Plutonium Reactor Experiment—*see p. 24*] program, the molten-salt reactor experiment, the beryllium oxide reactor experiment, the high-performance liquid-metal reactor experiment which is an offshoot of the terminated Aircraft Nuclear Propulsion program [the Pratt & Whitney molten lithium reactor, which AEC is considering converting to central station use: NU, May '61, 21], the ultra-high-temperature gas reactor experiment which is evolving from the Turret project, and the reactor experiments which have not yet been clearly identified to give us information on the nuclear and engineering performance characteristics of coated particle fuel and of systems in which heat is transferred from unclad fuel to coolant by radiation through barrier walls."

JCAE Chairman Chet Holifield (D-Calif.) reacted warmly in mulling over Seaborg's proposals. He told NUCLEONICS that reintroduction of Gore-Holifield-type proposals for federal construction of power prototypes depended primarily on the final form of the fiscal-1962 AEC construction budget voted by Congress this year (*page 18*). Specifically, they depend on whether generating facilities costing $95-million for the controversial Hanford New Production Reactor are voted this year. "If Hanford makes it," Holifield said, "that means things are going pretty well right now. If not, then we can start talking about a federal construction proposal to get on with the program."

At the subcommittee hearing on the authorization bill, Rep. Jack Westland (R-Wash.) objected during Seaborg's presentation to a federal reactor building program. "If you could solve the reactor site and safety problems," Westland said, "you could be building right now the Southern California Edison, the Pacific Gas & Electric and the Los Angeles–Pasadena reactors. A number of projects would be moving." [The second of the three mentioned by Westland, PG&E, has been reported to be held up by economic, not siting, problems.]

Holifield's Views

In his APPA speech, Holifield began by emphasizing "that the de-

ESADA: Some Striking Thoughts on Nuclear Power

Some unusually interesting statements on nuclear power economics were made last month by Empire State Atomic Development Associates, Inc. (ESADA), the seven-utility group in New York State which is sponsoring high-temperature reactor development at General Atomic and General Electric (NU, Jan '61, 20). The average ESADA power cost of 7.5 mills/kwh for modern fossil plants is typical of several areas of the U. S. The ESADA comments:

On fossil technology: " . . . it must be recognized that the design of conventional power plants has improved to the point where it seems unlikely that further technical advances will continue to offset rising fuel costs."

On large power stations: "There is a definite trend in conventional power plant practice toward large stations. In the case of atomic power plants, the savings in the capital cost per unit of power output are even more pronounced. Indeed, it now appears that, in all but isolated instances, the ability to absorb blocks of generating capacity of 300,000 to 500,000 kilowatts is a prerequisite condition for early achievement of economically competitive atomic power."

On reactor proposals to ESADA last year: "Specific proposals were received for the research, development and construction phases of projects keyed to a 1967 or 1968 target for plant startup. Analysis of these proposals led to the conclusion that if the development work proposed were successful, competitive atomic power could be achieved on this timetable. Three principal factors were found to account for the indicated improvement in atomic-power generation costs [over an estimated 9 mills for a plant starting up in 1965]: 1. increased plant size (from 300,000 kw to 400,000 kw or more), together with related engineering improvements; 2. higher thermal conversion efficiency due to improved steam conditions; 3. improved atomic-fuel fabrication and utilization."

On the general outlook: "Atomic power stands on the threshold of becoming an influential factor in the energy economy of New York State. If the present momentum of progress in atomic power development is maintained, there is a distinct possibility that a level of performance competitive with conventional thermal stations will be demonstrated in actual plant operation before the close of the present decade."

AEC Authorization Bill Totals $227.5-million for '62

AEC formally submitted its fiscal-year 1962 construction program to the Joint Committee on Atomic Energy last month—asking authorization for a total of $227.5-million in new or expanded projects, including $114-million for the Stanford accelerator, $95-million for generating equipment at the New Production Reactor, $8-million for the Beryllium Oxide Reactor Experiment at Idaho (all of these projects covered in NU, May '61, 21), a $16-million increase for the Advanced Test Reactor at Idaho ($12-million for test loops, $4-million added building costs), $5-million for a plutonium-fuel-recycle pilot plant at Hanford Works, $6-million for new loops at the Experimental Organic-cooled Reactor, and $3.5-million to reinstate Turret, the proposed high-temperature gas-reactor experiment at Los Alamos which had been killed earlier this year (see page 24).

AEC also asked $7-million for research-development assistance on unsolicited power reactor proposals from the utility industry and $5-million for waiver of fuel-use charges. AEC General Manager A. R. Luedecke said unspent funds of $15-million for unsolicited proposals and $7-million for use-charge waivers are available to aid the 360-Mwe reactor of Southern California Edison, if AEC decides to give it support. SCE and Westinghouse now have formal proposals before the Commission, though siting of the reactor is still in question (the Marine Corps continues to oppose use of Camp Pendleton—NU, March '61, 24).

velopment of atomic power is no less important now than it was a few years ago . . . We should hasten this day [of wide use of nuclear power] to the extent that we can by initiating a positive and effective program to develop atomic power plants that are safe, reliable and economic.

"Our slow progress," the Joint Committee leader went on, "in my opinion has been primarily due to the adoption by AEC in 1954 and 1955 of an ineffective approach to solving these complex technical and economic problems . . .

"With the defeat of the Gore-Holifield bill, the so-called 'partnership' approach became the dominant pattern for the construction of atomic power plants. In my opinion, the decision to rely almost entirely upon this approach has delayed the development of atomic power . . . The 'partnership' approach seems to have run its course, at least as the main vehicle for development plant construction. . . .

"It seems to me high time that AEC move ahead with the development, construction and operation of a sequence of developmental projects aimed at achieving clearly-defined technical objectives according to a reasonably definite schedule . . . Once we get the NPR generating facilities authorized, and ascertain which of AEC's currently-authorized projects should go forward, I believe that AEC and the Joint Committee should have a little get-together to see where we go from here.

"I certainly would not preclude the construction of additional plants by the privately-owned utilities which they believe they are financially justified in undertaking, but the U. S. program should not be primarily dependent on such projects . . .

Holifield went on to declare that "during this developmental period it seems to me the federal government must carry the main burden of assuring strong public agency participation because of the unusual costs and economic risks involved. I believe that we do need an effective public effort in atomic power development in order to protect the public interest in this new source of energy."

JCAE officials said their first step would be to reconstitute the task force which worked on JCAE's proposed ten-year reactor program in 1958. The original panel—whose members may or may not all be recalled—consisted of Walter H. Zinn, Henry D. Smythe, Chauncey Starr, Titus LeClair, and James Grahl (NU, July '58, 18). When the new panel has completed its review, AEC and JCAE leaders will get together.

Starr Committee

AIF's National Atomic Policy Committee held its organizational meeting in late April and reported to the Forum's Executive Committee that the policy study would center on peaceful nuclear power, with some possibility of getting into other areas of the nuclear program. Major tasks of the committee include a study of the entire energy-resource position of the U. S. and a questionnaire survey of the Forum membership on U. S. nuclear power policy. The several members of the committee were

Seaborg

Holifield

being asked to carry out study assignments with their own staffs.

Starr said the major considerations in the scheduling of the study—which he was asked to carry out by Forum President Charles Weaver of Westinghouse Electric Co.—were: the change of Administrations in Washington; recent statements of government officials constituting an "open invitation" for industry suggestions on U. S. nuclear policy; and "other minor considerations." Of the study effort, Starr said:

"It might be worth taking a look at the whole [energy resource program] to see where the country is headed. Our objective is very broad —we will be primarily concerned with the long-term goals of the atomic energy program. . . . Our committee is made up of people who are qualified to concern themselves with the problem, without calling in outside experts—essentially a committee which is supposed to represent the whole atomic energy industry."

The committee membership, predominantly utility and reactor-manufacturing executives, reflects the committee's chief interest—the civilian nuclear power program. The membership: Harold Quinton of Southern California Edison; Elmer Lindseth, Cleveland Illuminating Co.; W. Kenneth Davis, Bechtel Corp.; Lyman Fink, General Electric Co.; John Simpson, Westinghouse Corp.; Philip Sporn, American Electric Power Co.; Eger Murphree, Esso Research and Engineering; and Oscar Ruebhausen, New York City attorney.

Forum Regulatory Seminar Backs 3-Man Board Idea

The majority of an Atomic Industrial Forum group which recently met to review the regulation of reactors has given its support to a three-man board within AEC, which would adjudicate reactor-licensing cases right down to final decision. The new board had been proposed earlier this year in a regulatory study of the Joint Committee on Atomic Energy; a similar proposal had also been made by the Univ. of Michigan.

The Forum group also gave majority support to another JCAE-study proposal: the limitation of reactor review by AEC's Advisory Committee on Reactor Safeguards to novel safety questions. The group had met on Apr. 12 and, early in May, a summary of the meeting was sent to Forum members and AEC. The summary was particularly pointed on the role of ACRS in reactor safety and licensing. Some comments on ACRS:

". . . the ACRS has become the 'betenoire' of the AEC's regulatory processes. . . . To perform their difficult tasks in the limited time available, the ACRS has developed a basically standard form of brief report which varies from case to case only in the degree of enigma built into each letter [to AEC on specific projects]. The reports usually are not helpful to an understanding of the project because the bases for the Committee's conclusions are not set forth. . . . For a number of reasons the advice of the ACRS on a particular project amounts to a determination that a license will or will not issue. To some extent this result is a partial abandonment to the ACRS of the Commission's regulatory and policy-making responsibilities."

Proposed Board

Creation of the 3-man adjudicatory board—two scientists and one legal or judicial member—was expected to be explored during JCAE safety and regulatory hearings scheduled for mid June; JCAE scheduled the hearings to review the entire nuclear-regulatory picture and consider what kind of reorganization might be indicated, if any. The proposed 3-man board, though technically a part of AEC, would be appointed by the President. It would have final licensing authority and advise the 5-man Commission on licensing regulations. As discussed at the Forum meeting in April, ACRS would confine itself to particularly difficult safety questions and, possibly, review all power-and-test-reactor sites in their early stages.

Fermi Decision of U. S. Supreme Court Due in Few Weeks

On January 6, 1956—5½ years ago—the 25-company Power Reactor Development Corp. filed an application with AEC for permission to proceed with this country's first privately-sponsored fast-breeder reactor—the 100-Mwe Enrico Fermi plant which has since been completed at Lagoona Beach, Mich. (NU, May '61, 19). On Aug. 31, 1956—less than a month after AEC had given PRDC a construction permit—three labor unions* took the first legal step in seeking to have the construction permit rescinded.

This month or early next, the exciting chain-of-events which these moves touched off five years ago comes to a climax: The U. S. Supreme Court is to decide whether AEC legally permitted PRDC to construct the Fermi reactor and, in so doing, may say some things having much broader impact. The PRDC construction permit, which AEC later reaffirmed on a conditional basis, was voided early last summer by a Federal appeals court in Washington (NU, July '60, 21); that appeals court also held that there must be a "compelling reason" for locating any power reactor near a center of population.

Thus there were two major questions before the Supreme Court: 1. Is PRDC's construction permit legal?; and 2. Must there be a "compelling reason" for siting power reactors near heavily-populated areas? Ironically, both of these questions have been nearly mooted as the High Court approaches its decision. PRDC has placed itself on record as feeling, in effect, that it has gotten its money's worth whether or not Fermi is ever permitted to operate. On the "compelling reason" doctrine, AEC's attitude toward power-reactor siting has reached a point which all but embraces "compelling reason" even before the Supreme Court can review it.

On a third issue before the Court—arising directly from the arguments in the case—there may be a momentous ruling. This is the question of the extent of AEC's discretionary authority, under the 1956 Atomic Energy Act, to authorize construction permits, operating licenses, etc. The unions have been arguing that Congress limited AEC's discretion on construction permits by requiring AEC to pass on the likelihood of safe operation of a reactor before it had been built; the Justice dept., on behalf of AEC, has argued that AEC has authority to defer some safety questions until a reactor is ready for operation.

Fermi Case Milestones

January, 1956. Application of PRDC for license to design, construct and operate the 100-Mwe fast-breeder power plant at Lagoona Beach, Mich.

June, 1956. AEC's Advisory Committee on Reactor Safeguards said it could not be sure that Fermi could be operated safely at its site.

August, 1956. AEC issued a construction permit but recognized that certain problems would have to be solved prior to operation. Later that month, three labor unions* asked AEC to revoke the construction permit.

December, 1958. After hearings on the labor plea, AEC affirmed the construction permit, reserving the right to re-open the proceedings.

June, 1960. On appeal from AEC's decision by the unions, the Federal Court of Appeals in Washington, D. C., revoked the construction permit.

June or July, 1961. U. S. Supreme Court expected to issue its decision on the PRDC-Justice dept. appeal of the Appeals Court decision.

Oral Argument

The stage was set for a High Court decision when, on Apr. 26–27, the Court heard three hours of oral argument from the principals: Solicitor General Archibald Cox, arguing for the government; Benjamin Sigal, for the unions; and W. Graham Claytor, for PRDC. Oral argument is the last step before a decision.

Cox. The solicitor general, clearly well-schooled in the fundamentals of nuclear energy and of Fermi's design, spent a good part of his argument describing the plant and its core to the Court; he used a ½th-size model of the core to demonstrate its flow and structural characteristics, giving emphasis to the bird-cage design chosen to prevent bowing of the fuel elements. He also emphasized the "great hope" of increasing the world's energy supply with breeder reactors.

A meltdown of Fermi's fuel, Cox explained, would result in an explosion no greater than the equivalent of 600 lb of TNT and all resulting fission products would be completely contained by Fermi's pressure shell, which is rated at 1,000 lb of TNT. When Justice Brennan asked, "No effect of the explosion would get outside the shell?", Cox replied: "That is right." At another point, this exchange took place between Cox and Justice Frankfurter:

Frankfurter. "Do we sit in judgment on the conclusions of the Commission? Do we sit in judgment on the criteria which the Commission applied?" Cox: "You clearly do not pass [anew] on the Commission's findings and expert judgment. . . . There is no argument here that such findings as the Commission made were not supported by substantial testimony [during 1957 hearings on validity of the construction permit]. There is some argument as to what the findings mean." Frankfurter: "Maybe they [AEC] judged whether these safeguards were adequate by distorting what a safeguard means."

Cox based his contention of AEC legality in issuing a conditional construction permit on Sec. 50.35 of AEC's regulations. This rule provides for issuance of a construction permit "on a provisional basis" whenever a project's nature renders it impossible for the applicant to furnish all technical information—provided there is reasonable assurance that the "general type" of reactor can be operated safely and that all necessary information on the specific reactor is eventually provided. "We are asking

* United Automobile, Aircraft and Agricultural Implement Workers of America; International Union of Electrical, Radio and Machine Workers; and International Union, United Paperworkers of America—all of the AFL-CIO.

Argue Fermi Case Before Supreme Court

Unions' Sigal

PRDC's Claytor

U. S.'s Cox

you to rule," Cox said, "that there was reasonable assurance that a reactor of the type proposed could be operated . . . without danger to the . . . safety of the public." He later commented: "Congress delegated the health-and-safety responsibility to the Commission."

'Compelling Reason'

Of the three attorneys, only Cox mentioned the "compelling reason" issue. Since this issue was not thus joined during the oral argument, it may not be considered by the Court. Cox, himself, mentioned it only briefly, with the comment that the doctrine could be found nowhere in the '54 Act.

Sigal. The hour-plus appearance of the labor attorney was marked by much questioning by the Court (during the entire three-hour argument, only one of the nine justices asked no questions—Clark). The Court was particularly interested in Sigal's argument that AEC had violated both the Act and its own rules in limiting its health-and-safety finding to "the purposes of this construction permit." Sigal said this had the effect of stating that the act of construction could be carried out safely, while AEC should have been passing on the likelihood of safe operation when Fermi was finished.

He agreed that AEC would again review Fermi's safety when PRDC applies for an operating license but, he insisted, this in no way relieved AEC of its alleged responsibility for barring construction of a plant unless it had reasonable assurance that the plant could be operated safely at its location.

"The greatest potential hazard," Sigal said, "lies in the possibility that the accumulation of fission products imprisoned in the core . . . might somehow—including a breach in the containment—be released into the atmosphere and be distributed by the wind. . . . These are more toxic than any other industrial material, by a factor of a million to a billion."

Sigal agreed with Justice Whitaker that "the government has the authority to say: 'This is not safe; we will not permit you to operate it.'" But Sigal added: "As we see it, it is essential that the Commission make a finding at the start before there is an investment of $50–100-million."

Among Sigal's other arguments: **1.** he noted that the government had had to provide power-reactor indemnity of up to $500-million per reactor after the insurance industry could provide only $60-million ("That, in itself, indicates the horrendous possibility of an accident."); **2.** he noted AEC's two "conflicting functions"—promotion and regulation—with AEC, in this case, providing developmental funds to PRDC while simultaneously regulating its activities ("That is an open invitation to schizophrenia. . . . We think this double function must have a very substantial impact on the way the Commission handles its regulatory responsibilities."); and **3.** accused AEC of being ambiguous in its findings on the construction permit ("We are left to choose between conflicting inferences in the Commission's own words and—more than that—the Commission did not follow the law.").

PRDC attorney Claytor, in an argument that lasted only 15–20 minutes, came up with something of a surprise: he said the PRDC sponsors had already gotten "a great deal of information" for the research-development dollars they invested in the project. Thus, he argued, there would be no pressure on AEC to permit operation of the plant and "the money has been written off as research-and-development expenditures."

"Should Fermi turn out less successful than we had hoped," he explained, "it will not be constructed as a failure—because we have already compiled a great deal of information. . . . There is no possibility that, should this plant not be permitted to operate, there would be pressure brought to bear on the Commission. . . . It would not be a white elephant. We have already decided an enormous number of metallurgical and other problems which would be of value to future reactors."

On the legality of the construction permit, Claytor argued that AEC had applied a valid approach to power reactors which are developmental—implying that, when power-reactor technology passes the developmental stage, conditional construction permits might not be necessary. On this question Claytor made two points: **1.** unless AEC had discretion on developmental reactors, the utility industry might not be able to participate in reactor construction; and **2.** regardless of its policy on construction permits, AEC had the power to bar operation of any reactor at any time, on safety grounds. The court will act by fall at latest.

AEC Reorganizes Reactor Development Div.; New Offices Stress Civilian-Reactor, Advanced-Reactor, Safety Areas

AEC's Reactor Development div. began to function last month under a basic re-organization plan. At mid-month the reshaping had not been officially announced. But General Manager A. R. Luedecke had given Division Director Frank Pittman an okay to operate under the new organizational concept pending Luedecke's formal approval. These features characterized the re-organization:

- Civilian Reactors and Advanced Reactors sections are cast in more important and essentially new roles. Each will get additional manpower and be headed by an associate division director, a title one step higher than the present assistant directors for the various reactor offices—which includes the military reactor offices.
- A new safety office to develop experimental reactor safety information is to be set up within the Division. The work of this office will be to develop data under controlled experiment conditions which would define maximum credible reactor accidents. Maximum credible accidents previously have been postulated on the basis of theoretical calculations, but the new office will operate a destructive-testing facility to determine such data on a number of different reactor cores experimentally. Construction on the facility is planned for a fiscal-1963 start at the National Reactor Testing Station. Joel Lieberman, now chief of the Division's Environmental and Safety Engineering branch, it is understood, will become chief of the new office.
- The Advanced Reactors section will be headed by Jack Armstrong, former deputy director of the airplane, rocket and SNAP programs. Les Staebler, now senior assistant director to Pittman, was understood to be the choice for the associate director's post for the Civilian Reactors section. Both will have "sign-off" responsibility for all projects under them. Formerly, Pittman made all the final decisions.

A special contract-administration "trouble-shooting" office has been established under Staebler. The special mission of this office is to relieve the regular technical staff of time-consuming administrative details not directly related to research-development. Keeping AEC's civilian power reactor projects on schedule would fall under this office.

According to Pittman's ideas, the Advanced Reactors section is to concentrate on long-range development possibilities ordinarily lost in day-to-day activities. Government development work on new concepts would be contracted for by this office from the concept itself through the proof-of-principle stage.

Brazil's New Atom Chief Moves to Expand Nuclear Program

Brazil's new nuclear chief, Prof. Marcelo Damy de Souza Santos, is charting a considerable expansion of Brazil's nuclear power plans. Two small demonstration power reactors are being considered for addition to the program, and the Mambucaba River project, originally envisaged as a 150-Mwe reactor, is now being restudied as a station of either a single 350-Mwe reactor, or twin units of 150–200-Mwe each.

Appointed by new President Janio Quadros to take over leadership of the National Nuclear Energy Commission (NU, April '61, 30), Damy has responsibility for perhaps the leading—certainly one of the two leading—national nuclear programs in Latin America. Brazil has two operating research reactors: a 5 Mwth Babcock & Wilcox pool (Latin America's first reactor) at the Univ. of São Paulo Nuclear Research Institute, of which Damy had been director until moving to NNEC this winter, and a Triga at the Univ. of Minas Gerais at Belo Horizonte. An Argonaut, under construction in Rio, is to be completed in eight months. The country is rich in thorium, and has done considerable work on nuclear source-material processing. For her first power station, planned last year for the Mambucaba River site (NU, Aug. '60, 30), world-wide invitations for proposals were to be issued last September, but this was postponed for the review under way.

The Mambucaba site, 85 mi west of Rio de Janeiro, has been dropped because of unfavorable geologic conditions and insufficient flow in the river for reactor cooling. The new site has yet to be chosen. Internuclear Corp., Clayton, Mo., and Kennedy & Donkin of London, are helping Brazil draft new specifications. The project is taking on aspects of a crash program: target date for completion of the first station is still late-1965. "It will be met," Damy declares. Although Brazil's long-range program calls for use of thorium–U-233 breeders, it is considered questionable whether this first station would be thorium fueled because of the short time schedule.

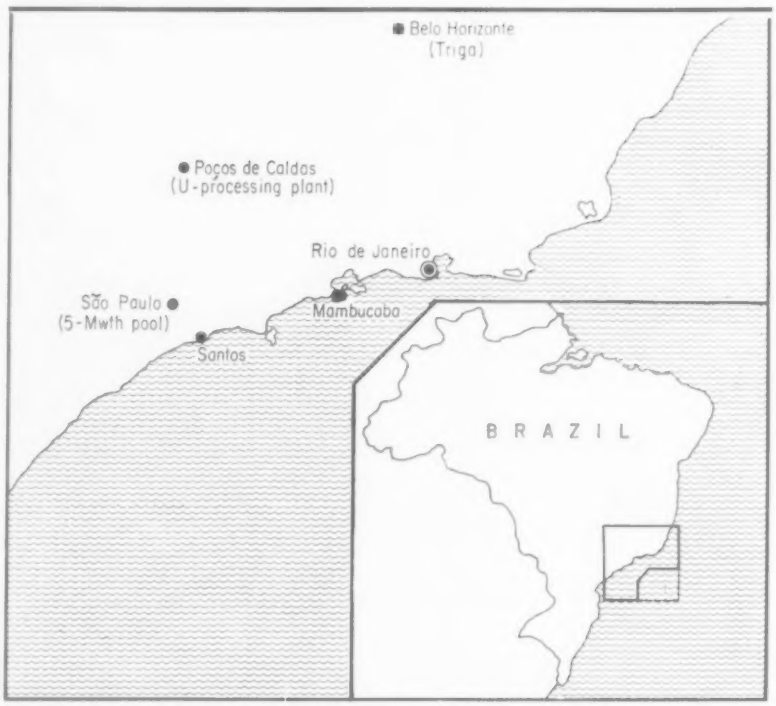
Of the 2 small units under study, one would be a 15-Mwe unit, probably using the thorium cycle, to be built at São Paulo. It is described as the first power reactor to be designed and built in Brazil, and would be in operation by 1965. The other would be 20 Mwe, possibly larger, fueled with either U-235 or thorium; it is to be built in northern or northeastern Brazil, and is also to start up by 1965. (A study team has just recommended that it be a 50–100-Mwe unit, bought abroad.)

Basic goal of the NNEC, Damy told NUCLEONICS, is to carry out a program to make Brazil self-sufficient in nuclear fuel and reactors within the next five years. To this end, NNEC is being completely reorganized, he said, and will function under the newly-created Ministry of Mines and Energy. Despite big new hydro projects soon to be completed, the main population and industrial center —the Rio–São Paulo–Minas Gerais region—will need another 1.1-million kw by 1965. The region's present installed capacity is about 2.6-million kw. Of the new capacity, about 400,000 kw is to come from thermal or nuclear sources. Despite an economy drive, President Quadros has given high priority to nuclear development.

Damy estimates cost of a 350-Mwe reactor at "not less" than $65-million, but says local funds are assured from government sources and local Brazilian and foreign power companies. Foreign financing offers have been received.

Three possible sources of fuel are seen. 1. If enriched U is used at first, the existing U. S.-Brazilian bilateral accord, providing for supply of fuel for a 10-Mwe reactor, would have to be broadened. 2. Brazilian scientists have developed a process for deriving nuclear-grade U from sodium uranate; but obtaining sufficient quantities to fuel a large reactor by 1965 is not considered probable. If the first big station is natural-U fueled, the uranium would probably be imported. 3. NNEC has already bought a plant for refining thorium from monazite, and considerable theoretical and experimental work on the thorium cycle has been done at the São Paulo Institute.

Plans for construction of a uranium-ore processing plant at Poços de Caldas will be updated (originally it was to have been built by France's Societé de Terres Rares to specifications drawn up in 1952).



French Cold-Storage Magnate Leading Commercial Effort To Perfect Irradiated Potatoes and Other Foodstuffs

A Frenchman who is making his fortune in cold-preservation of food—and who thus might ordinarily be expected to be quite prejudiced against radiation preservation—is spearheading the most advanced commercial food-irradiation program in the Free World. He is Pierre Vidal, president of a cold-storage and food-packing firm in Lyons and founder-president of Conservatome, a food-irradiation firm established by more than 30 French food and agricultural companies.

Largely because of Vidal and Conservatome, French irradiation technology is far enough along technically and economically—as against psychologically and regulatorily—to introduce irradiated potatoes to the French consumer within a year. Conservatome has taken potato irradiation to the pilot-plant stage and Vidal estimates that commercial quantities could be irradiated to inhibit sprouting for less than 0.5 cents/lb (cobalt cost of $1/curie)—an attractive cost to potato marketers because of over-compensating weight savings.

However, irradiated potatoes have been neither cleared by the French health authorities for human consumption nor, of course, yet tested against the consumer-resistance barrier inherent in radiation-treated food. Between these two factors, the marketing of irradiated potatoes in France appears to be several years away.

Nevertheless, it is significant that the French impetus has been commercial, rather than governmental; the food industry will not have to be talked into radiation preservation by the government but, instead, awaits only governmental clearance to proceed, first, with potato irradiation and, eventually, other food products (Vidal says grain deinfestation is just behind potato irradiation). By contrast, the U. S. high-dose food program has been dominated by the military and the low-dose program, just getting underway (NU, Jan '61, 23), is funded by AEC. For both programs, mass consumption of any irradiated food appears so remote that it is rarely even discussed anymore; and if and when this form of food preservation is perfected, the food industry may have to be convinced—to some extent—even before the consumer is approached.

Conservatome Program

Vidal first irradiated food products in 1954, using the spent-fuel pit at EL-2, the first experimental reactor at Saclay. Conservatome was formed in 1956, installed a 625-curie, cobalt-60 source at Lyons and, as of early this year, is operating a 3,000-curie cobalt pilot irradiator near Lyons at Dagneux, in conjunction with a dozen non-food companies (the entire operation, also founded by Vidal, is known as CLAA—Centre Lyonnais d'Applications Atomiques).

Over this eight-year period, the experimental program has included onions, meat, milk, eggs, jam, fruits, grain and even mustard—at doses from 1,000 rads to several million—with Conservatome operating the facility and acting as a clearing house on work of the member companies.

Potato irradiation attracted Vidal as commercially promising early in the program. France's crop totals about 15 million tons/yr and weight loss during storage is about 20%, most of it caused by sprouting. In 1958, Conservatome had enough data on radiation dose and the proper post-harvest irradiation period to run an extensive test on that year's crop. Several hundred pounds of the variety which constitutes 60% of French production were irradiated 3–4 weeks after harvest at doses of 7,500, 10,000 and 12,500 rads; intensity was 108,000 r/h at 60 deg F.

After a year in storage (a well-ventilated dark room at 50 deg F and 85% relative humidity), none of the potatoes irradiated at 10,000 and 12,500 rads had sprouted; the 7,500-rad lot had begun weak sprouting at 10 months. Untreated potatoes stored under the same conditions had sprouts exceeding the limit for consumption after six months.

Conservatome's first cooking and taste tests were made with the 1959 crop; 10,000-rad samples were compared with untreated potatoes stored at the traditional 40 deg F and with potatoes a month old. Cooking times were 20 min for untreated potatoes, 16 min for the irradiated samples and 15 min for the new potatoes. The untreated potatoes from storage were lumpy, hard to mash and dark yellow in color; the irradiated potatoes remained firm, easy to mash and of the same light-yellow color of the new potatoes.

Lyons is a gastronomic center of France and eight local citizens tested the untreated and irradiated storage potatoes. Boiled in their jackets and eaten unsalted, the irradiated potatoes won easily, with no trace of an "earthy" flavor characteristic of a long-stored potato. In mashed and french-fried form, the two lots were rated about equal. Last year, the French Army began toxicity tests—feeding Conservatome-irradiated potatoes to rats.

When the 1961 crop comes in early this summer, Conservatome expects to irradiate a ton of potatoes at Dagneux, plus a half ton of grain. These will go for further wholesomeness tests expected to take irradiated food another step closer to the market in France.

Government Approval

The French have a two-step procedure for regulating the marketing of irradiated food: 1. an interministerial commission must approve the use of the radiation source involved; and 2. the Public Health Ministry must approve consumption. The public-health body, in turn, gets advice from the National Council on Hygiene and the Academy of Medicine.

Food-Irradiation Activity Widespread in Europe

Western Europe as a whole is doing much work on food irradiation, with about sixty research centers active and the general emphasis on low-dose irradiation. Both France and Great Britain have pilot-plant installations but the British facility, Wantage (NU, Feb '60, 100), is used only incidentally for food irradiation. The Germans, doing both applied and fundamental research, expect to have in operation by the end of this year a fairly elaborate food-irradiation facility at Karlsruhe. Low-dose sprout inhibition of potatoes (story this page), medium-dose irradiation to destroy salmonella bacteria in eggs, and deinfestation of grains are the three applications closest to commercialization.

The Food Irradiation Study Group of the European Nuclear Energy Agency is trying to establish itself as a European-wide food-irradiation focal point. Under its aegis, an international panel is to be formed to work out safety, regulatory and other ground rules for international acceptance of food and non-food products (such as medical supplies) treated with radiation. The ENEA group may eventually, as well, sponsor the fabrication of European food irradiators.

The most advanced potato-irradiation program is in the Soviet Union, where, according to Western officials, some 100 tons of potatoes are being marketed annually; radiation source is a 25–50,000-curie, cobalt-60 facility (NU, Nov. '59, 25).

REACTOR NEWS

YANKEE: 11–13-MILL POWER ON FIRST CORE?

This is the optimistic outlook of the Yankee reactor's operators, reported at an all-day symposium in New York on early operating experience with the Rowe, Mass., plant. The forecast is significant because early estimates of a few years ago had, at their most optimistic, predicted a possible power cost of 12–14 mills/kwh, but only with the third or fourth core. "We are in a much better frame of mind now," the symposium was told. "If we can stay on the line at full power for at least 7000 hr/yr, we can wind up in the 11–13 mills/kwh range. Further cost reductions can result from increasing output, increasing core life, and reducing fuel-cycle cost." Output has already been increased from 120 to 125 Mwe gross (= 116 Mwe net) without exceeding the licensed reactor power of 392 Mwth, as the reactor is proving slightly more efficient than predicted. And permission has been asked of AEC to increase power to 485 Mwth—145 Mwe gross, 136 net.

TWO MORE FIELD REACTORS FOR ARMY

Two Army reactor projects, a new and an old, made news last month. The Corps of Engineers asked Congress for authorization to order its sixth*—and smallest—field reactor in fiscal-'62: ML-1A, first field version of the ML-1 (Mobile, Low-power) which went critical in Idaho March 30 and will go to full power (300–500-kwe) this fall after its gas turbine is delivered. . . . Meanwhile, an undisclosed number of bids of MH-1A (Mobile High-powered), the barge-mounted reactor project, was received by the Corps of Engineers, in a second round of bidding after first-round bids were thrown out (NU, April '61, 21) in an effort to get estimated $17-million cost closer to the Engineers' own estimate nearer $12-million. Among those bidding in this new round—for a first-phase, 6-months' design contract, with options on succeeding phases leading to operation in 1965—were known to be Maryland Shipbuilding & Drydock with Martin Co.; Todd Shipyards, Alco Products, and George G. Sharp Inc.; Sun Shipbuilding with Allis-Chalmers; and Electric Boat division of General Dynamics, Rawls Bros. shipyard at Jacksonville, Fla., and Walsh Construction Co., New York, each of the last three with Westinghouse. Only first-phase design funds, about $600,000, are available.

PROPOSALS ASKED ON 50-Mwe OMR

AEC has asked for proposals by July 24 on the 50-Mwe Improved Cycle Organic Reactor. The bid follows an earlier call for expressions of interest, to which nine utilities responded (NU, March '61, 31; summary of responses in NU Wk, 16 Feb '61, 2). The invitation goes to cooperatively- and publicly-owned utilities generally, and specifically to those four of the nine whose responses are considered promising: Burlington, Vt.; Dairyland Power Coop, LaCrosse, Wis.; Grand River Dam Authority, Vinita, Okla.; and Plains Electric Generation & Transmission Coop, Albuquerque, N. M. The Advisory Committee on Reactor Safeguards has already approved the sites proposed by these four. The five others have been informed by AEC wherein their proposals fell short, but may propose if they choose.

TURRET PROJECT REINSTATED

AEC has restored funds to build the Turret high-temperature gas-cooled unclad-fuel reactor at Los Alamos Scientific Laboratory—largely on the urging of New Mexico's Sen. Clinton P. Anderson, vice-chairman of the Joint Committee on Atomic Energy. $3.5-million in new funds is provided for reinstating Turret. Turret had been dropped earlier this year (NU, March '61, 31).

LAMPRE CRITICAL

The Los Alamos Molten Plutonium Reactor Experiment, five years in development and construction (NU, Feb. '56, 14), started operations in April at 950° F. A fast breeder and believed to be the world's first molten Pu reactor, LAMPRE uses a eutectic plutonium-iron alloy (90% Pu) contained in 138 tantalum thimbles 8 in. high, ⅜ in. dia, to make a 6 × 6-in. active core; each thimble contains 170 gm Pu-Fe. Molten sodium is coolant.

DRESDEN, EBWR CRITICAL AGAIN

Dresden returned to operation April 20 following replacement or modification of control rod blades and rod drive components. Down since Nov. 15, 1960 (NU, May '61, 25), Dresden will now be put through a low-level critical testing program to calibrate the worth of the new control rods and also to determine the characteristics of the proposed Core-2 fuel using 12 developmental Core-2 elements. . . Argonne's veteran Experimental Boiling Water Reactor returned to criticality after extensive modifications to permit 100-Mwth. The attempt to reach 100 Mw will not be made until later this summer, after two reboilers have been installed.

RESEARCH REACTORS ORDERED, COMPLETED

Northrop Corp. will buy a Mark-F pulsing type Triga for its Norair Division's new Space Radiation Laboratory, Hawthorne, Calif. It will be used, on completion late this year or early next, to simulate radiation conditions in studies on the effects of space radiation environments. For General Atomic this is its 23d Triga, and its first sale to a commercial concern. . . Lockheed has sold a training reactor—a 0.5–1-kwth pool—to Purdue Univ., for spring 1962 completion. Lockheed's winning bid (of 12) was $106,000. Lockheed previously sold five small reactors. . . AMF Atomics completed its 15th research reactor when Portugal's 1-Mwth pool went critical at Sacavem near Lisbon.

NAVY: D1W STARTED, 10 MORE S5Ws

A program to develop a naval reactor that can be used in single units, rather than pairs, to power a true destroyer (2,500–3,500 tons) has been started at Westinghouse's Bettis Lab. It is called D1W. The Navy's first nuclear destroyer-leader, *Bainbridge*—launched at Quincy, Mass., April 15—requires two D2G (General Electric) reactors and consequently a 7,600-ton hull to house them—the size of many a small cruiser. . . The Navy issued contracts for primary-loop components for ten S5W submarine reactors, for the ten Polaris units in President Kennedy's acceleration program. Five went to Westinghouse, for $27,130,000; five to GE, for $26,639,600. The GE job will be handled by the submarine procurement group MAO—Machinery Apparatus Organization—set up last winter as a counterpart to Westinghouse's Plant Apparatus Division to share the load (and compete) with Westinghouse in building S5W reactors. . . Meanwhile the Navy's fleet of operational nuclear subs grew to 20 as three more went to sea. *Sculpin* and *Scamp* are sisters of *Skipjack*, *Thresher* is first of the improved-*Skipjack* class; she immediately set a new deep-diving record first time out.

* Earlier ones include PM-2A, in operation in Greenland; SM-1A, nearing completion in Alaska; PM-1, to be installed at Sundance AFB, Wyoming, this summer; PM-3A, to be delivered to McMurdo Sound, Antarctica, this winter; and PL-3A, requested of Congress early this year for construction at Byrd Station, Antarctica.

WORLD NEWS

Westinghouse, Berlin in Design Pact

The electric utility of the enclave-city of West Berlin, BEWAG, was one of the possible starters for the first round of the U. S.-Euratom power program, but did not make the Oct. 20, 1959, deadline. Last month BEWAG chose partners for the forthcoming second round—and Westinghouse had the coveted assignment. BEWAG gave a design contract for a 150-Mwe pressurized-water reactor, for end-1965 completion, to a team of Westinghouse, reactor; Siemens, turbogenerator; Kaiser Engineers, architect-engineer. There is no commitment to build. Construction, if decided on, would have to begin no later than early 1963 to meet the completion deadline. The plant would be an improved Yankee or SELNI model; one of the chief purposes of the design study will be to determine the appropriate balance between pioneering and new advances, on one hand, as against reliability on the other hand in a location so "far from home" and so difficult of easy access as West Berlin. BEWAG is a stock company; 57% of its shares are held by the City of [West] Berlin, the rest privately.

Bonn to Subsidize KBWP Reactor

Another step forward for nuclear power in Germany came when the Atomics Ministry in Bonn agreed to subsidize KBWP—the Stuttgart group, successor to AKS, planning to build a 150-Mwe organic-moderated power reactor (NU, May '61, 26). The governmental aid, to the tune of $400,000, will enable KBWP to plan and issue specifications for the plant. Atomics International is now working on preliminary design of the reactor; Brown Boveri will design the over-all plant, to be built at Obrigheim near Mosbach, Baden, 40 mi north of Stuttgart. The station is to begin operating in mid-1965. Total cost is set at $65-million, of which Euratom will contribute $27.5-million, the European Relief Program $9-million, and the West German federal government a further $25-million.

CENUSA Proposing Two 250-Mwe Reactors

CENUSA (Centrales Nucleares S. A.), one of Spain's two nuclear utility groups, has filed for official permission to build one of two large power reactors it has long been planning, and will shortly file on the other. The first would be built at a loop in the Tagus River at Castrejon near Toledo, for 1968 completion, the second near Seville to be finished by 1970. Each would have an output of 250-Mwe, each is budgeted at $53-million, and for neither has the reactor type been chosen. Pressurized water, boiling water, or Calder-type gas cooled are possibilities. The Castrejon station would be financed entirely by three of Spain's largest electric utilities—the three members of CENUSA. Nuclenor (Centrales Nucleares del Norte), the other group, has already asked permission to build a station in the north.

British See Big Advance: Concrete Vessels

In what is seen in England as one of the greatest single advances in the British gas-cooled and graphite-moderated reactor systems, affecting both Calder-type and AGR (Advanced Gas-cooled Reactor) designs, British reactor manufacturers are proposing an arrangement in which the entire primary coolant circuit is totally enveloped in a single cylindrical prestressed-concrete pressure vessel. This radically new containment concept slashes capital cost, dramatically modifies the whole hypothesis of reactor safety and siting, and improves the thermal characteristics of the system. In addition, use and accessibility—and replaceability—of steel prestressing cabling removes several of the major uncertainties and deficiencies associated with large steel pressure vessels and their suspected long-term irradiation effects. A major cost advantage of the envelope design is its compactness, leading to cumulative savings of a civil-engineering nature. Direct savings are also inherent in a structure in which the concrete biological shielding and steel pressure shell are integrated. Steel cable can more easily be made to metallurgical specification than thick steel plate. Savings will also accrue from reducing gas ducting by orienting heat exchangers closely about an unshielded core. Higher coolant pressures, to 400 psi, and higher temperatures, are possible, improving thermal efficiency. Finally, postulated consequences of failure are less drastic: with the entire primary contained, worst effects of a burst duct—rapid loss of pressure and coolant—are eliminated.

At least two consortia are reported ready to submit envelope designs for the next nuclear station, Oldbury. But neither the Central Electricity Generating Board nor the consortia will comment on the development, details of which are still regarded as top secret. Nevertheless, the general impression is that the attitudes of both CEGB and the Atomic Energy Authority appear favorable to the new concept.

France was pioneer of the prestressed-concrete pressure vessel for reactors, with the two huge horizontal concrete pressure-shells enclosing the cores of G-2 and G-3 at Marcoule; EDF-3 at Chinon also will have a concrete reactor vessel. But the concrete encloses only the core, not the entire primary.

Euratom Plans Financial Aid for Reactors

A proposal to apply $19-million from Euratom's research budget to help any power reactor under construction or planned—specifically SENN, SIMEA and SENA—is on the agenda of the Euratom Consultative Research Committee meeting. The proposal states that any nuclear enterprise may apply for aid if it contributes to promotion of European nuclear industry, acquisition of knowledge, or creation of skills, and if the enterprise is willing to put certain information at the disposal of Euratom. The money could be used for fuel-element fabrication, supply of fuel, manufacture of reactor components in European countries, or meeting extra startup costs as compared with conventional power plants. SIMEA, SENN and SENA have already applied for such aid—all three for fuel fabrication, SENN and SENA also in addition for covering expected deficits during initial operation. The plan clearly represents a determined effort to use research-program facilities for industrial development, to hasten the time when the infant European nuclear industry can break from the U. S. AEC's apron strings. For example, the proposal would provide aid on fuel fabrication "provided the process involves at least conversion of uranium metal and cladding elements into fuel elements ready for use in the reactor" if this is done in Euratom countries; aid would be increased by one-third if refining of concentrates and preparation of uranium metal were also done in Euratom.

Australia, Formosa Start Research Reactors

Two more U. S.-built research reactors abroad have gone critical: Nationalist China's first reactor, a 1-Mw General Electric pool, started up April 13 at Tsing Hua Univ. 20 mi south of Taipei. Australia's second, a 10-kw American Standard UTR (Argonaut type), went critical April 12 at the Lucas Heights nuclear center.

NEWS IN BRIEF

SL-1 Core Confirmed as Dry; Pittman Group Meets

In late April, AEC's Advisory Committee on Future Use and Disposition of SL-1—headed by Reactor Development Director Frank Pittman—held its first meeting since shortly after the SL-1 explosion in January (NU, Feb. '61, 17, 22). Committee members said confirmation of a dry core (NU, May '61, 23) indicated that the dismantling operation would not be too complex but that more information on radiation in the building was necessary before a dismantling program could be decided upon; it also appeared possible that SL-1 would be returned to operation after it is cleaned up. Radioactivity in the building had dropped from the range 500–1,000 r/hr to 30–200 r/hr by late April. Among the dismantling alternatives under consideration were: direct entry to the core in the near future, assuming radiation levels drop fast enough; remote removal of the core immediately; and a delay of a year or so if this is necessary to permit direct entry.

General Electric's Idaho Test div. was selected by AEC in early May to carry out the decontamination and disassembly program when it is finally laid out. GE and AEC's Idaho Operations Office were negotiating a cost-plus-fixed-fee contract calling for assignment of about 70 people to the task for 9–12 months.

California Firm to Operate Commercial Burial Site

The first commercial land-burial site for radioactive waste (low level) is to be operated 100 mi northwest of Las Vegas, Nev., by Nuclear Engineering Co., Pleasanton, Calif. The site will supersede temporary AEC service at the National Reactor Testing Station and Oak Ridge National Laboratory. Looking toward start of operations by July 1, Nuclear Engineering is negotiating a burial contract with AEC and a lease with the State of Nevada covering, for 99 years, an 80-acre site within a 46,000-acre desert area near Beatty, Nev. The company also expects to build a decontamination and repair facility at the site.

AEC Licensed-Reactor Survey Finds No Big Problems

AEC reported in late April that a post-SL-1 survey of reactor licensees (NU, Feb. '61, 23) had turned up no major problems. Object of the survey was to obtain a broad picture of reactor-safety procedures and assure against inadvertent criticality. Since announcing the survey results, however, AEC ordered the Univ. of Wyoming to shut down its training reactor (after an Apr. 25 visit by an AEC inspector when no licensed operator was on duty). Principal findings of the survey: 1. all measured maximum reactivity values were in agreement with the licensees' hazards reports; 2. no reactor could go critical on withdrawal of one control rod (as could SL-1); and 3. procedures involving core-reactivity changes were satisfactory. AEC was further investigating unspecified reactors where nuclear instrumentation was not always in use when changes affecting core-reactivity during shutdown were made; in some cases, it is felt, use of the instrumentation may not be necessary.

Seaborg Supports Non-nuclear Work at Natl. Labs

AEC Chairman Glenn T. Seaborg has given his support to a proposal earlier this year by Alvin M. Weinberg, director of Oak Ridge National Laboratory—use AEC's national laboratories for important non-nuclear research-and-development programs (NU, March '61, 33). In a speech to the American Physical Society in late April, Seaborg said the labs could well advance the national interest by doing work on: long-range transmission of electricity; better control over environmental pollution; long-range prediction and control of weather; desalinization of briny water; exploitation of ocean minerals; biophysics and biochemistry; and national resources.

Seaborg also called for "extended effort and additional [government] support" in low-energy physics research. "Funds and facilities must be made available for vigorous work in low-energy nuclear physics whenever and wherever there are capable groups interested in carrying out such programs. No field of basic research is more ideally suited for the development of young scientists at our universities." He said he intended to give attention "in the coming months" to the need for new and the replacement of old low-energy accelerators at "our colleges and universities."

AEC Adopts Access Rule on Gas Centrifuge Work

An access-permit program for gas ultracentrifuging technology (NU, Sept. '60, 17) has been formally adopted by AEC; the process is of growing commercial interest in the separation of heavy isotopes, including uranium-235. AEC imposed these restrictions on those granted access to AEC's information: demonstration of a capability and "serious interest in" making a "substantial effort" to engage in centrifuge development; reports to AEC on development results during and for one year after expiration of an access permit; all development data over a parallel period must be available to AEC inspection; a grant to the government, upon request, of a non-exclusive, irrevocable, reasonable royalty-bearing license (for government purposes) on any patent, discovery, etc., during the same period; and a grant to AEC of the right to use, for AEC programs, any proprietary data developed during the same period, subject to payment of reasonable compensation.

Firms wanting to build or operate a gas-centrifuge plant would have to obtain appropriate AEC licenses. Preliminary steps toward such licenses have been taken by Thor-Westcliffe Research, Inc., Sante Fe, N. M., and Decker Corp., Philadelphia.

Two Forms of Indemnity Agreement Adopted by AEC

AEC has adopted two forms of indemnity agreement into which it will enter with licensees required to maintain public-liability insurance or another form of financial protection; there is a form for each type. A third form —for nonprofit institutions not required to maintain financial protection—has been proposed for public comment by June 20. A major problem in the indemnification area has been the "common-occurrence gap," where an accident exhausts some or all of the commercial liability insurance available to a licensee. AEC decided to close the gap by reducing its indemnity "floor" of $60-million per facility to the level at which an accident might cause commercial indemnity to terminate.

AEC Asks Interest Indications On Process-Heat Unit

Expressions of interest from organizations using process steam have been invited by AEC; the expressions are due by June 19 at AEC's Chicago Operations Office, Argonne, Ill. AEC would build the reactor and—"as a minimum"—the user would provide site and steam-utilization facilities, and operate the plant and purchase the steam for five years. The reactor would be rated at 30–45 Mwth, with steam pressures from 15–200 psi; final specifications would follow determination of the user. Detailed proposals would be invited by AEC if the expressions of interest support this.

RADIATION NEWS

Hughes Aircraft Gets Order for Sterilization Plant

A turnkey order for an entire radiation-sterilization plant has been given to Hughes Aircraft by an undisclosed customer. By the end of this year, Hughes is to furnish a 10-Mev linear accelerator, its housing and all associated equipment, including conveyor system. The firm was undecided whether to use its own staff as architect-engineer or to bring one in as a subcontractor. Hughes said the customer did not want to disclose either its name or the product to be sterilized but that the customer chose radiation over the alternative sterilization medium for economic reasons; the sale was Hughes' first for a commercial production accelerator. The company is also designing a "compact" linac of 10-Mev intensity for medical therapy and radiography; the prototype is to be completed later.

Curtiss-Wright Claims Major Advance in Co^{60} Sources

A major advance in the design of cobalt-60 radiation sources has been claimed by Curtiss-Wright. C-W is using the design for more than 400 solid-cobalt rods to be irradiated at Savannah River for the Army Quartermaster Corps's Food Process Development Irradiator (under construction at Natick, Mass.). The rods, first batch of which were shipped to Savannah in late April, are double-encapsulated—first in stainless steel, then in highly pure aluminum, with a total clearance estimated to be less than 1/1,000th in. for both claddings. If no defects show up in irradiation, it will not be necessary to decan and recan the cobalt, precluding the need for remote-handling equipment normally required for these operations; only helium leak-testing and removal of surface contamination would be required after irradiation. The close-tolerance techniques of double encapsulation could be readily applied to any shape, C-W contends.

The Natick FPDI, key facility in the Army's food-irradiation program, is to be completed early next year. In addition to the 1,1-megacurie cobalt irradiator designed by C-W, FPDI will also have a 24-Mev linear accelerator built by Varian Associates and a food-handling annex.

Univ. of California Enters Civilian Food Program

AEC has formally brought the Univ. of California at Davis into the Civilian Food-irradiation Program as the second research center. Massachusetts Institute of Technology is the first—concentrating initially on low-dose irradiation of haddock and clams under refrigeration (NU, Jan. '61, 23). Davis, using a 30,000-curie cobalt-60 irradiator identical to the one AEC is supplying to MIT, will work on low-dose irradiation of strawberries, citrus, tomatoes, grapes and peaches. The idea is to introduce radiation to the normal processing program for these fruits—rather than substituting radiation for some other step—and thereby increase the shelf-life and marketing capability. First-year contract between AEC and Davis is $64,000. Still unsettled was the possibility of a third irradiation center at the Univ. of Seattle—for research on marine products processed in that area.

Hanford Fission-Product Shipment Puts F3P on Line

Oak Ridge's Fission Product Pilot Plant (F3P) has gone back into 24-hr, 7-day operation, following the successful cross-country shipment in April of 120,000 curies of cesium-137 and 20,000 curies of strontium-90. Origin was the Hanford Works operated for AEC by General Electric. F3P was processing the strontium first, hoping to deliver it to Martin Co. in titanate form by mid-June for loading into a 105-watt remote weather station. Martin is to install the station in northeastern Canada, for the U. S. Weather Bureau, this summer—the first radioisotopic generator to go into regular service.

Meanwhile, AEC was reported considering an invitation to industry on the construction and operation of waste-separations capacity at Hanford. Martin Co. and Air Reduction Co., as a team, have been studying this possibility for more than a year (NU, Apr. '60, 31). AEC is expected to have a round of bidding this year on separations proposals; of major interest are the radioisotopes required for isotopic-power sources, including strontium-90.

AEC Invites Comment on Tritium Use in Auto Locks

A proposal to use tritium for illuminating automobile locks has prompted AEC to ask public comment "on the general question whether it should authorize the use of radioactive materials in consumer goods where control over the disposal of the radioactive materials cannot be exercised, even though the radiation dose to individuals in the population may be extremely low compared with natural background radiation." A petition to exempt auto-lock illuminators (those containing no more than 15 millicuries of tritium) from AEC licensing requirements was filed with AEC by a Bernard Heinz, Scranton, Penna. There would be no external radiation from the device; thus, AEC said, there would be no hazard, provided the devices were built to manufacturing specifications AEC would establish. AEC estimated that the use of tritium in all potential luminous products would no more than approach tritium radiation now occurring in nature. AEC recently approved the use of tritium in timepiece dials, but as a substitute for radium, which gave off considerably more radiation. Comments on the tritium question are due by about June 25.

RMI Perfects Irradiated Wire, Looks to Polaris

Radiation Materials, Inc., a joint venture of Radiation Applications, Inc. and Loral Electronics Corp., both of New York City, said last month it expected in the near future to be selected the second supplier for irradiated polyolefin hook-up wire used in the Polaris missile; Raychem Corp., qualified last year as the first supplier (NU, Apr. '61, 32). RMI said it would probably complete eligibility tests in May for the Polaris' builder, Lockheed Aircraft Corp., and would demonstrate production capability by the end of June; both specification conformity and production capability must be demonstrated to qualify. RMI was proceeding with a "crash program," under General Manager David Sahud, to get into wire production for Polaris and other missiles and space vehicles either committed to irradiated wire or on the verge of such commitments.

Lockheed Getting into Nuclear-instrument Field

A Lockheed Aircraft group in the Georgia div. has been given management clearance to enter the nuclear-instrument field. Robert Butenhoff, acting manager of the Division's Nuclear Measurements dept., is directing the program, with emphasis on custom instrument systems such as a special 400-channel analyzer sought by White Sands Proving Ground, N. M. "We will come out with a line or products but our major effort is to try to satisfy certain system requirements," Butenhoff explained. The department is already marketing ionization chambers and intends to get into the manufacture of a scaler, amplifier, pre-amplifier and other modular-type components recently developed. "We have a lot of capability when we join forces with Lockheed Electronic Products [New Jersey] and the [Lockheed Missiles and Space div., Sunnyvale, Calif., builders of Polaris]."

SPACE NUCLEONICS

Gatlinburg Meeting: Finger Urges Mars-Venus Push

Nuclear Rocket Manager Harold B. Finger, of AEC and the National Aeronautics and Space Administration, highlighted a nucleonics-in-space conference at Gatlinburg, Tenn., last month with the suggestion that the nuclear-rocket program be oriented toward beating the Russians to Mars and Venus. "Although it could not be done in this decade," he said, "perhaps we must aim our program for Mars and Venus. We may not beat the Soviet Union to manned lunar landings—because of their head start—but we should be able to plan a program to beat them to the planets. Our program would, therefore, be a long-range one with the moon as a preliminary objective and the near planets as our ultimate objective. Under these circumstances, the nuclear-rocket system would have to be our major propulsion development." Finger declared: "We believe that we are ahead of the Russians in the development of nuclear propulsion systems and we, therefore, believe that we can beat them in the long-range space program." Other highlights of the Gatlinburg meeting:

Reactor Flight Test. Finger disclosed that all four contractors under the Reactors-in-Flight-Test program (RIFT—NU, Jan '61, 21) have recommended that first flight tests take place at Cape Canaveral—with a nuclear stage boosted by a Saturn chemical vehicle. "Such a flight test approach," Finger noted, "could lead to the development of a Saturn vehicle with a nuclear third stage [Saturn D (NU, May '61, 22)]." Flight-test target for the first nuclear rocket is in the timespan 1965–67.

Von Braun. Wernher von Braun, director of NASA's Marshall Flight Center, gave the Gatlinburg audience a 90-min briefing on the Saturn program. During a question period, he had some interesting comments on whether nuclear rocketry should be accelerated to help the U. S. "leapfrog" the Soviet Union on booster capability: "I believe that the nuclear-rocket propulsion program has a tremendous future, insofar as our long-range program is concerned. . . . Once we have it we will be able to do things we cannot do with chemical rockets. [However] if the task is to beat the Russians in the next few years, I do not think we should look to the nuclear rocket. . . . It is a very fine thing for the day after tomorrow. . . . However, if you are going to have something tomorrow, you are going to have to do something today." Von Braun also said he believed "that the future of the nuclear rocket lies in upper stages—not in ground-launched vehicles," primarily because of the psychological problems associated with terrestrial flights.

Does Your Company Have A Market In The Nuclear Industry?

Then it should be listed in the 1961–62 annual November NUCLEONICS Buyers' Guide to nuclear products, materials and services. Free listings in the Buyers' Guide are based on questionnaires sent to companies by NUCLEONICS. If you did not receive a questionnaire in 1960, then write to

Buyers' Guide Manager, NUCLEONICS
330 W. 42nd St., New York 36, New York

giving the company address and the name and title of the person who can best categorize the products and their nuclear applications for your company.

Fast Rocket Reactors. Ralph S. Cooper of Los Alamos, reporting indirectly on LASL's interest in fast reactors for rocket propulsion, said this reactor type offered considerable promise in the low-power range (1–2,000 Mw). Comparisons with both chemical and graphite-reactor systems indicated that fast reactors would offer payload advantages in satellite or deep-space applications via a combination of low weight and high specific impulse. Possible core materials, he said, included: uranium dioxide (which melts at 2800 deg C), uranium monocarbide (2450 deg), UO_2 dispersed in molybdenum (2600 deg) or tungsten (3370 deg), and higher temperature forms of uranium monocarbide (for example, zirconium carbide). Cooper indicated that LASL had not yet mounted a substantial development effort on fast reactors, devoting most of its nuclear-rocket energy to the graphite reactors of the current program.

Tungsten-184. Seymour A. Levin of the gaseous-diffusion group at Oak Ridge reported on an economic study—requested by NASA's Lewis Research Center—on enriching tungsten in its isotope-184 for use as a nuclear-rocket core material (*see story below*). Enriched tungsten offers higher operating temperature (and, thus, higher specific impulse) than graphite—and lighter weight, as well. Also, because its low absorption of neutrons means a reduced requirement for enriched-U fuel, "much of the cost of separating the tungsten isotopes" should be offset, according to Levin. ORNL could produce fully-enriched tungsten-184 for $4,000/lb in a new gaseous-diffusion plant, Levin reported; large scale production in existing facilities would cost only $1,500/lb (78% enrichment); and limited production in the range 60–81% enrichment would cost $2,330 to $9,430/lb, depending on enrichment.

Ohio Congressman Criticizes Restrictions on NASA

Rep. Charles A. Mosher (R-O.) complained in late April that NASA, at its new Plum Brook materials testing reactor (NU Wk, 30 March '61, 3), was unable to proceed with nuclear-rocket fuel experiments it would like to carry out—because of a dispute with AEC on jurisdiction over reactor development. Mosher thus brought out in the open a sensitive situation which has existed since last summer, when former AEC Chairman John A. McCone and former NASA Director Keith Glennan worked out a "memorandum of understanding" on the nuclear-space responsibilities of the two agencies. NASA has interpreted the memo as barring it from fuel-element development, including experiments planned for Plum Brook. Lewis has been particularly interested in developing tungsten cores for small water-moderated, gas-cooled and fast rocket reactors (*see story above*).

As of now, Plum Brook has been restricted to non-fuel experiments. However, Mosher reported that the new leaders at AEC (Glenn T. Seaborg) and NASA (James Webb) were trying to work out an arrangement more acceptable to NASA.

House Space Group Restores Nuclear-Rocket Funds

The House Science and Astronautics Committee last month reinstated $23.5-million in NASA's fiscal 1962 authorization request for the nuclear-rocket program; the funds must be appropriated after the authorization step. The total includes $8.5-million for support of the engine-development contractor to be brought in soon (NU, May '61, 22) and $15-million for engine-test facilities at Jackass Flats, Nev. If another $7-million sought by AEC is also reinstated, some $90-million would be available for nuclear-rocket development in fiscal '62.

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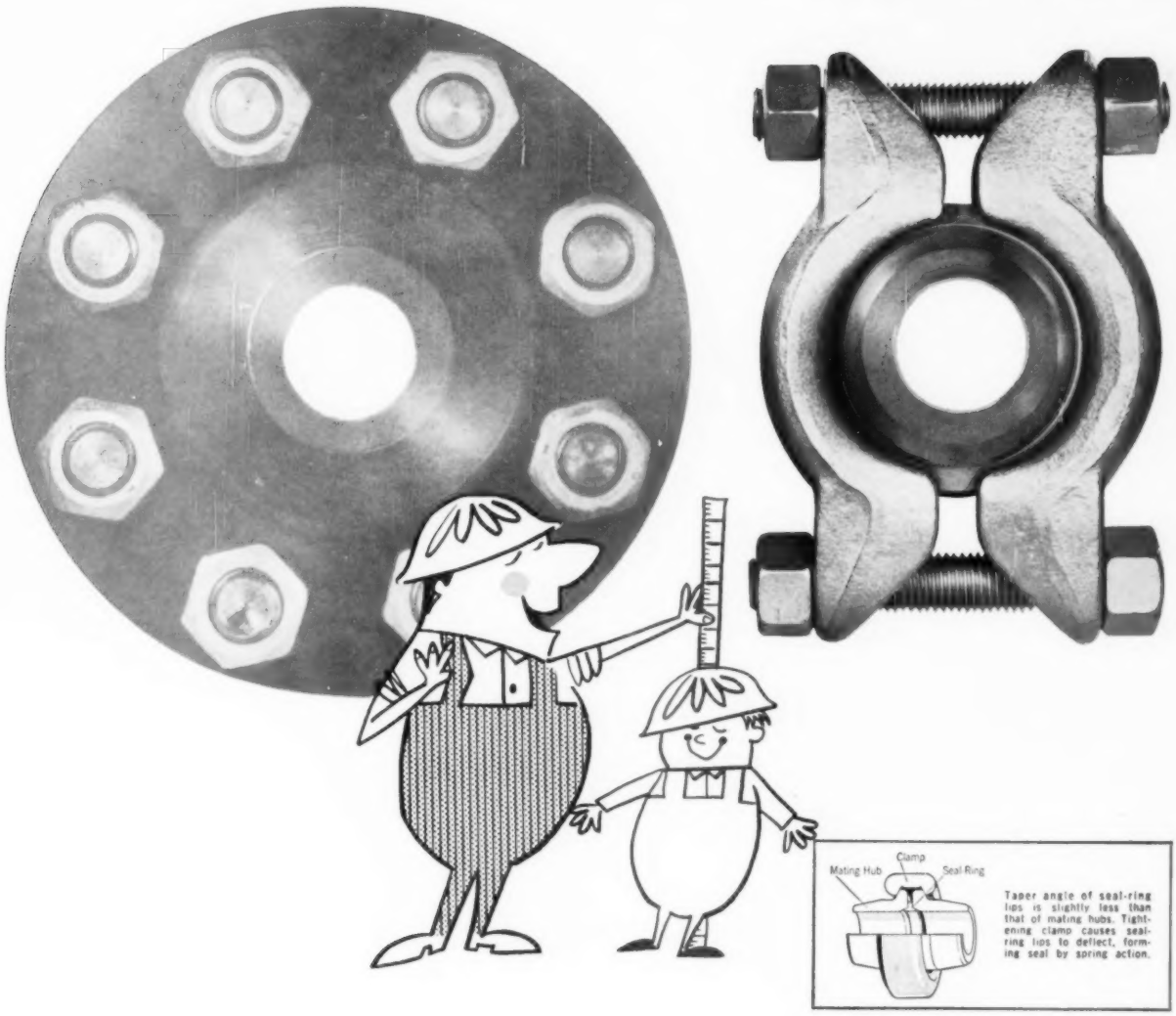
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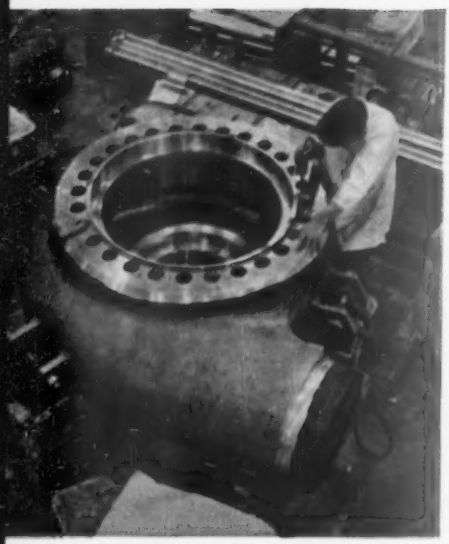
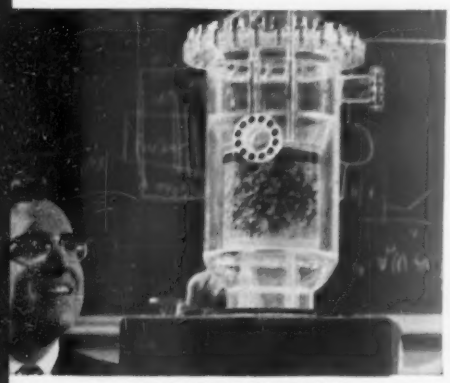


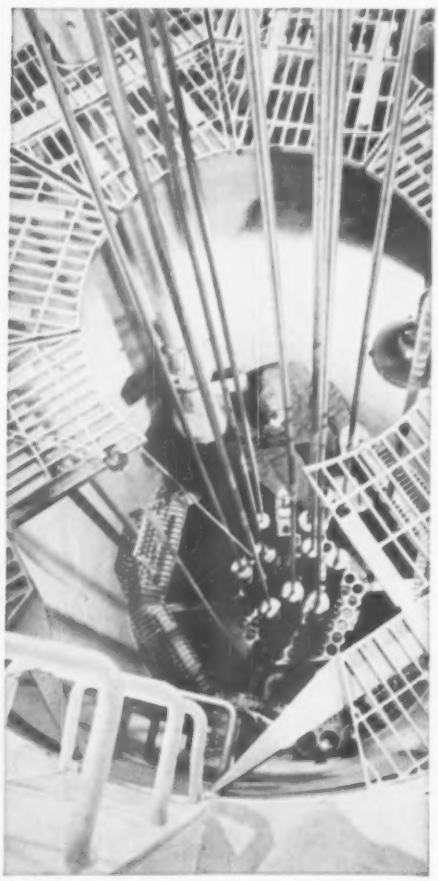
Westinghouse Quality Control inspector is working on a nine ton stainless steel pump casing at the Atomic Equipment Department in Cheswick, Pa. Department produces canned motor pumps, valves and control rod mechanisms.

Electron Beam Welding of core components is one of the many special skills employed at the Atomic Fuel Department, Cheswick, Pa. Standard products of the department are reactor cores and their components.



Dr. James H. Wright, shown here with an organic moderated fluidized bed reactor model, is also doing important development work on the concept of an integral boiling and superheat reactor (IBSHR).

Westinghouse Engineers, after design, follow through on construction of reactor plants such as this 5,000 kilowatt plant being built at Saxton, Pa., for the Saxton Experimental Corporation. This new reactor will be used with an existing turbine generator at the Pennsylvania Electric Company site.



Critical Experiment Station at Testing Reactor. This technician is working in the low power test facility used to confirm physics calculations by experiments before exposure in the reactor.

Westinghouse Testing Reactor facility includes hot cells and metallographic cells for post-irradiation examination of samples. Nuclear fuels and other materials can be tested inside cylindrical fuel elements of reactor core. Chemical, analytical and counting laboratories are used for post-irradiation tests.

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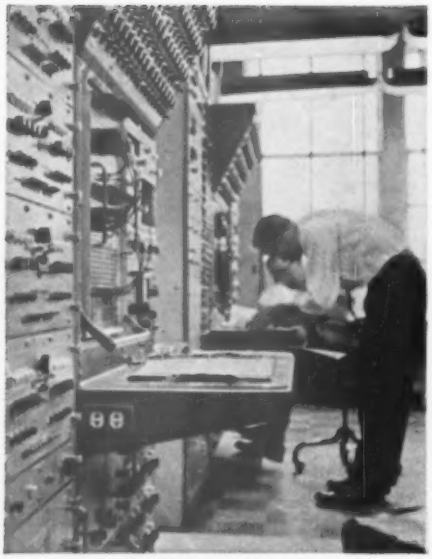
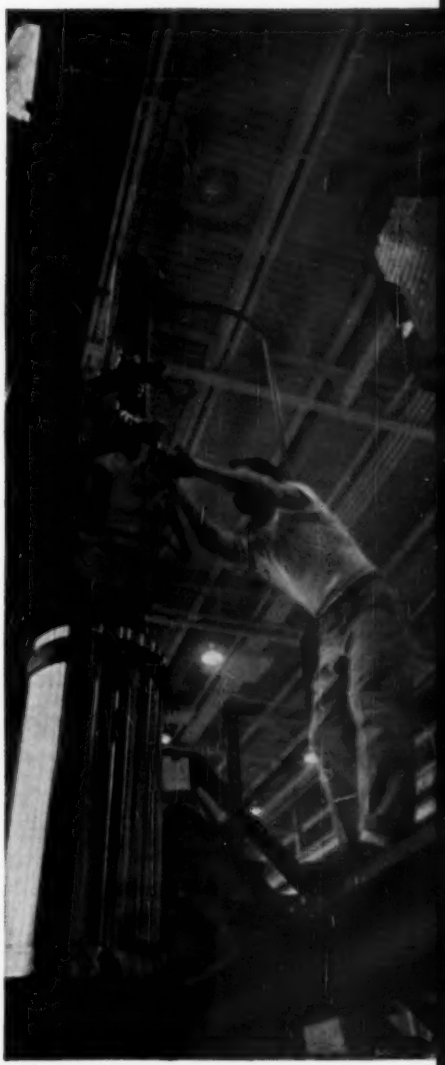


Westinghouse Mathematicians are working out the solution to a nuclear fuel problem at this computer installation in the Atomic Power Department at Forest Hills, Pa.

Dr. W. E. Shoupp, Technical Director of the Atomic Power Department, plays vital role in developing atomic fueled plants to the point where they will be economically competitive with fossil fueled plants in the generation of electric power.



Skilled Machinist is working on the shell and flange for a canned motor pump on a 120" vertical boring mill at the Atomic Equipment Department.

Dr. Joseph C. Danko heads up promising advanced research of the thermoelectric reactor, a potential means of generating electricity directly from fission heat without a turbine-generator unit.

Fuel Assembly Operation at the Atomic Power Department, where facilities are maintained for development of advanced fuel concepts. Technician is working on cage of a fuel assembly.

Dr. Sidney Krasik, Technical Director of Astronuclear Laboratory, works on applications of atomic power in outer space, such as nuclear power propulsion, the nuclear ram jet and auxiliary power plants for space vehicles.

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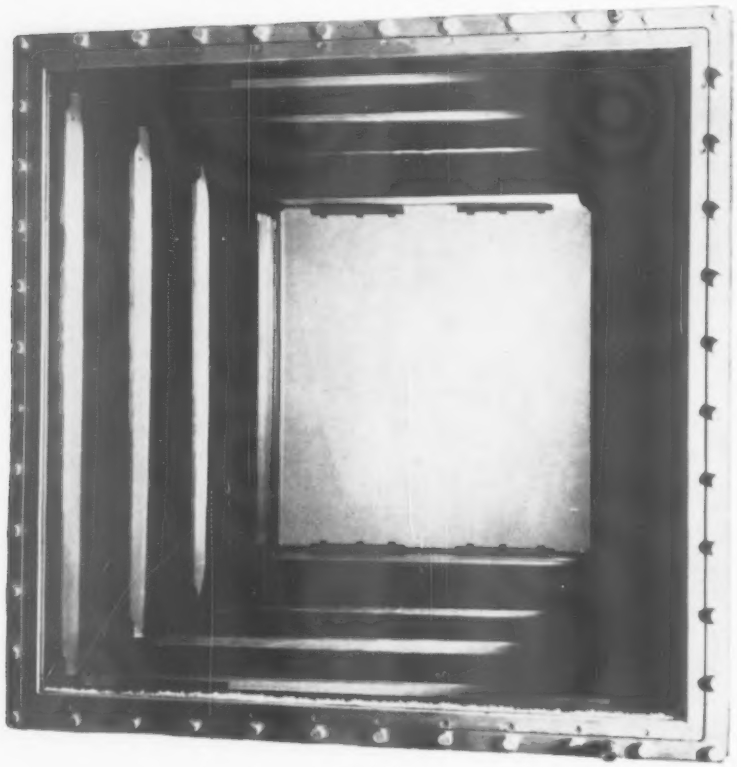

Window used in the E.D.F. power nuclear reactors at CHINON/France

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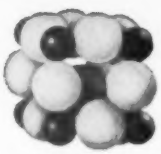
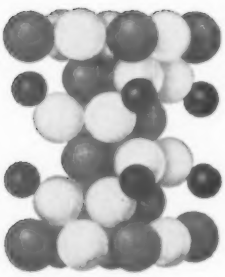
FROM RESEARCH . . .

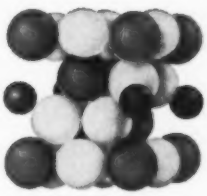
Interesting new compounds



Perovskite



Five layers



Three layers

A number of new oxide compounds with the perovskite structure have been developed by one of our research groups. Investigations of related three-layered and five-layered structures are also in progress. To discover the relationships between crystal structure and physical properties, intensive studies are being carried on to determine ferroelectric, ferromagnetic and dielectric characteristics. From this basic research may come advanced materials superior to any currently available. • Our corporate-sponsored research programs into the fundamental nature of matter offer *unusual opportunity* to any scientist interested in doing *original work*. Inquiries are invited particularly from those with experience in—Solid State Physics • Plasma Physics • Particle Physics • Nuclear Engineering • Gaseous Electronics • Direct Conversion • Surface Chemistry.

Please write to MR. W. R. WALSH, *Personnel Department:*

RESEARCH LABORATORIES
UNITED AIRCRAFT CORPORATION
400 Main Street, East Hartford 8, Conn.

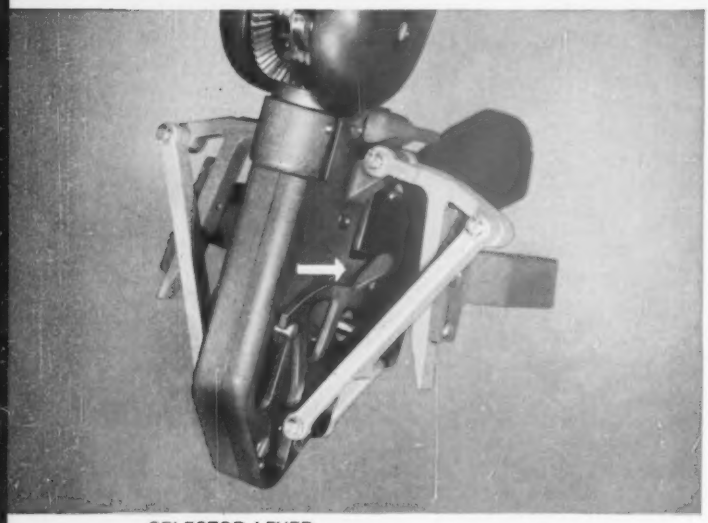
All qualified applicants will receive consideration for employment without regard to race, creed, color, or national origin.

HOW TO EVALUATE MASTER SLAVE MANIPULATORS

Here are questions and answers and a check list of features with which you can compare manipulators. It will help you to select the models best suited to your installation and requirements.

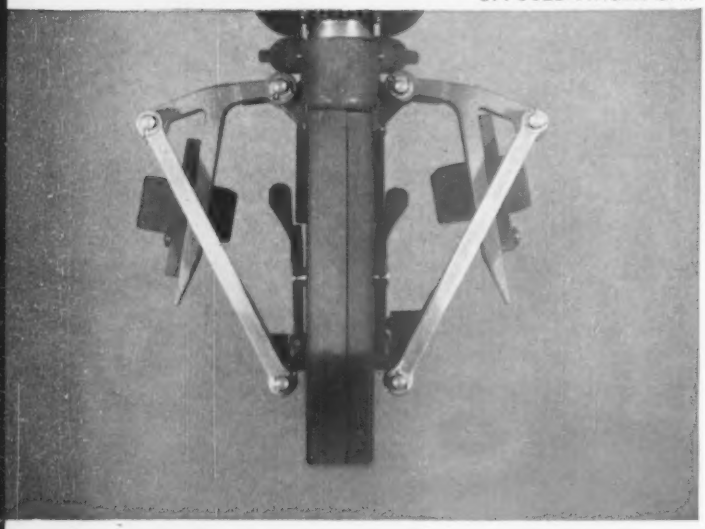
OPERATING CAPABILITIES

	Model 8 MSM	AMF SDMSM	AMF HDMSM
X-MOTION (Side to side)	30 LBS. (at normal operating extension)	100 LBS.	100 LBS.
Y-MOTION (back and forth)	30 LBS. (at normal operating extension)	100 LBS.	100 LBS.
Z-MOTION (up and down with load hook)	65 LBS.	65 LBS.	100 LBS.
MANIPULATION	5 LBS.	10 LBS.	40 LBS.



SELECTOR LEVER

OPPOSED FINGER GRIP



1. Is the biggest machine the best?

First of all, what are your needs? The full range of operation requirements should dictate your choice. There's no point in using a sledge for tack hammer service or vice versa. That is why AMF offers both a standard-duty and a heavy-duty manipulator. However, the heavy-duty "doubles in brass," providing standard-duty dexterity and heavy-duty load capacity.

2. Suppose my requirements change?

They very well might, and rapidly. This is why the AMF Heavy-Duty machine handles light tasks as well as heavy with a 1:1 ratio in normal operating range. Why change manipulators when flipping a selector lever will do the job?

Also, AMF Atomics can convert Model 8 manipulators for heavy duty service in minimum time with minimum expense.

3. What makes a manipulator a true "Master Slave" and what difference does it make?

If the tong movement exactly parallels the operator's (master's), the manipulator and operator have a master-slave relationship. That is why AMF Atomics manipulators have an *opposed finger* rather than a pistol grip, which was investigated and discarded by AMF some years ago. The pistol grip locates the operator's hands lower, and rotation around the wrist results in unnatural hand positions. Further, the increased distance from wrist to pivot point creates unfavorable leverage and makes weights extremely difficult to handle.

4. Steel or aluminum for boom and master trunk tubes? Which is better?

The comparison is this: steel has greater strength, but also much greater weight and therefore makes for operator fatigue. The heavier the boom tubes, the more counterweighting is required and, consequently, total inertial weight is still further increased. The question is, *how much strength is necessary?*

AMF Atomics believes that aluminum, because of its low weight (and high strength), is far preferable. It *does the job* (see chart) without need-

lessly burdening the operator. There's less weight to start moving, less to stop. Result: ease of operation without penalty!

5. What is the best rate of closure for the tongs?

Let's say first that the faster the rate of closure the less "feel" the operator has. This results from the force disadvantage in movement ratios higher than 1:1—say 1:2, 1:3 or 1:4. For light work the extra operator pressures are extremely tiring.

This is why AMF Atomics uses a 1:1 ratio for initial movements combined with a "double squeeze" system for increasing leverage. Again a 1:1 ratio is true, "normal," master-slave relationship.

6. What sort of service should I expect from my supplier-manufacturer?

Operations in nuclear science and industry can be "critical," not only in the special nuclear sense but also in the universal meaning of the term. Breakdowns can be *doubly* critical. That is why AMF Atomics takes these special steps and offers the following services:

a. AMF Atomics, by design and skilled manufacture, assures that the very minimum of service will be needed.

b. It provides a complete operation, maintenance and spare parts manual. The implications for minimum down-time are obvious.

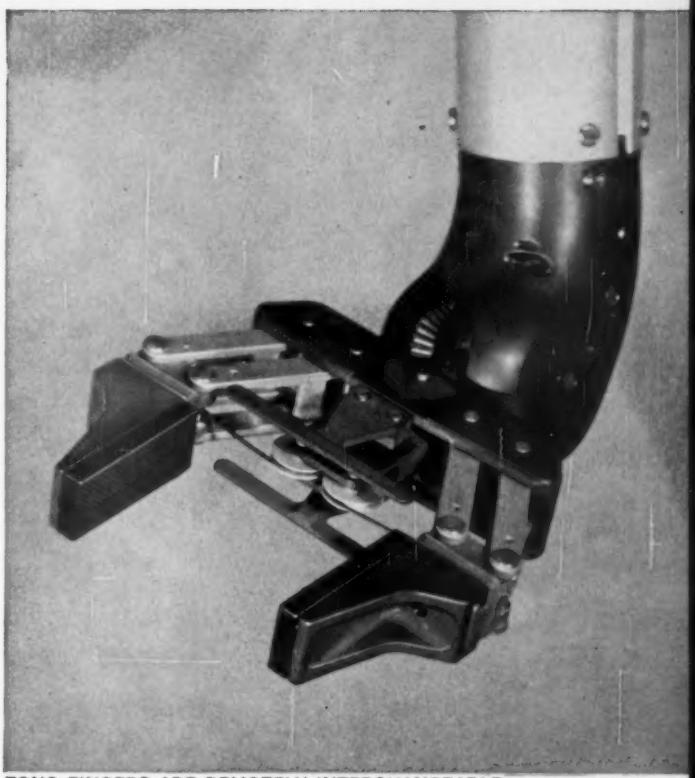
c. AMF provides technical field service that is constantly on call.

7. What about special requirements?

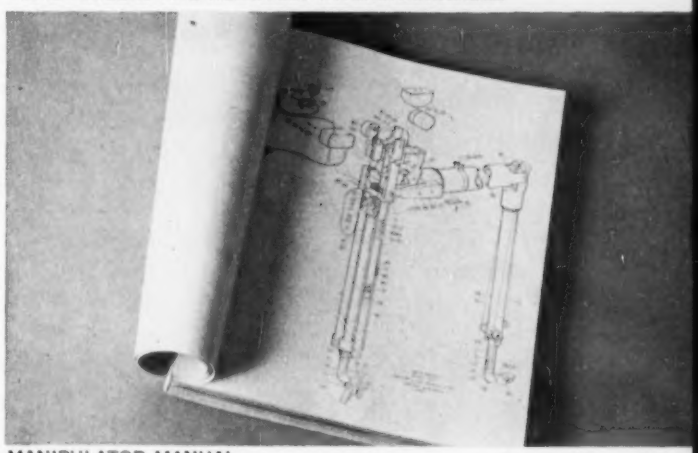
The wide range of AMF standard stock accessories eliminates most special requirements. However, if your problem is special, our engineers work with you to find the best solution at the lowest price.

AMF Atomics activities reach into all areas of nuclear science and technology, including: Research and Test Reactors; Reactor Refueling Equipment; Power Reactor Design; Nuclear Fuel; Remote Handling Equipment; Manipulators; Fuel Processing Equipment; Isotope Applications; Shielding and Radiation Studies; Reactor Control Systems; Training Reactors.

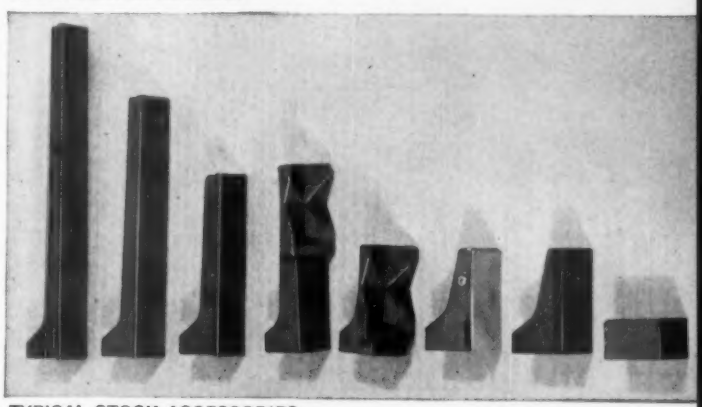
Please write for detailed information about any of these AMF Atomics products or services.



TONG FINGERS ARE REMOTELY INTERCHANGEABLE



MANIPULATOR MANUAL



TYPICAL STOCK ACCESSORIES

AMF ATOMICS

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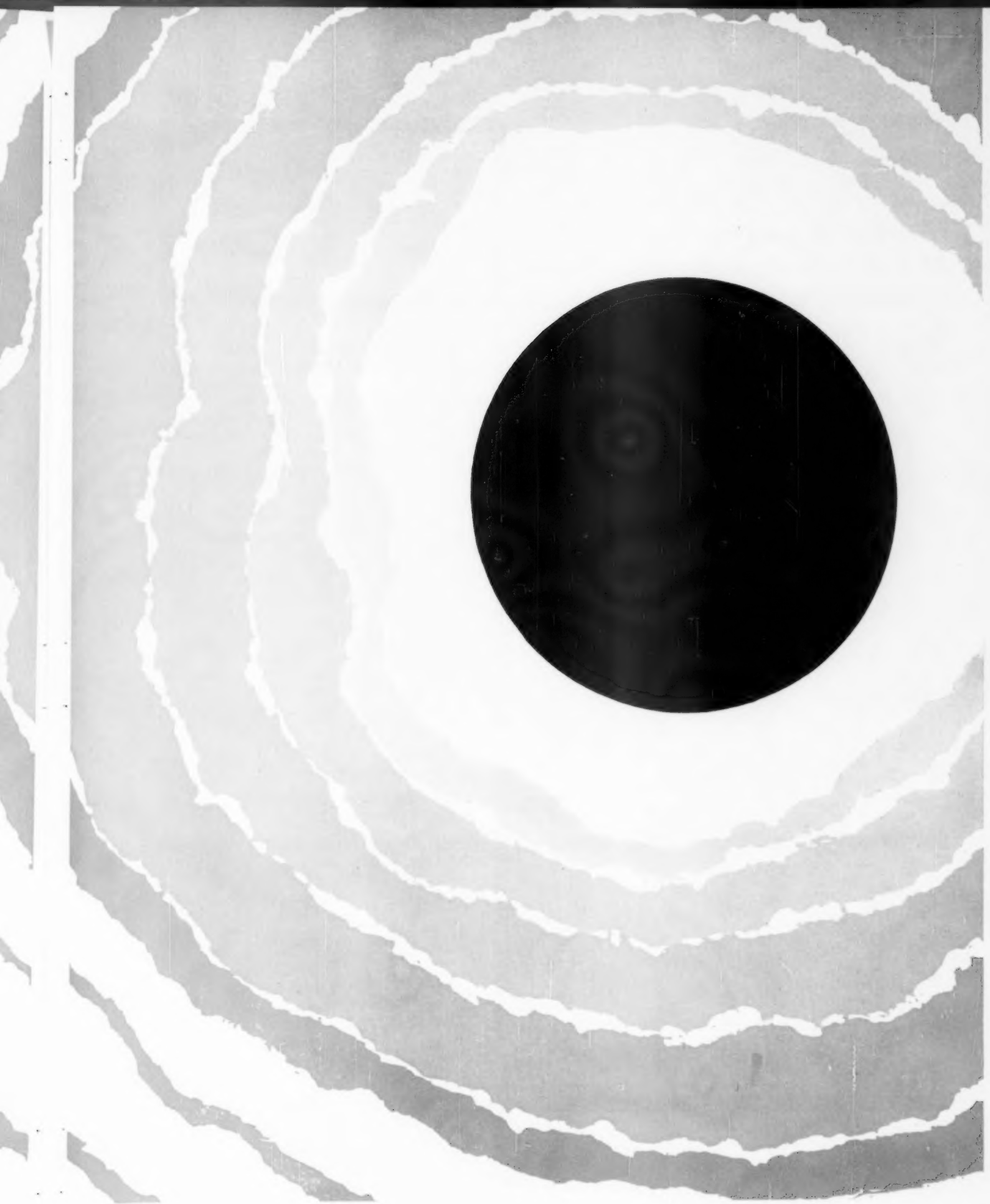

AMAZING!

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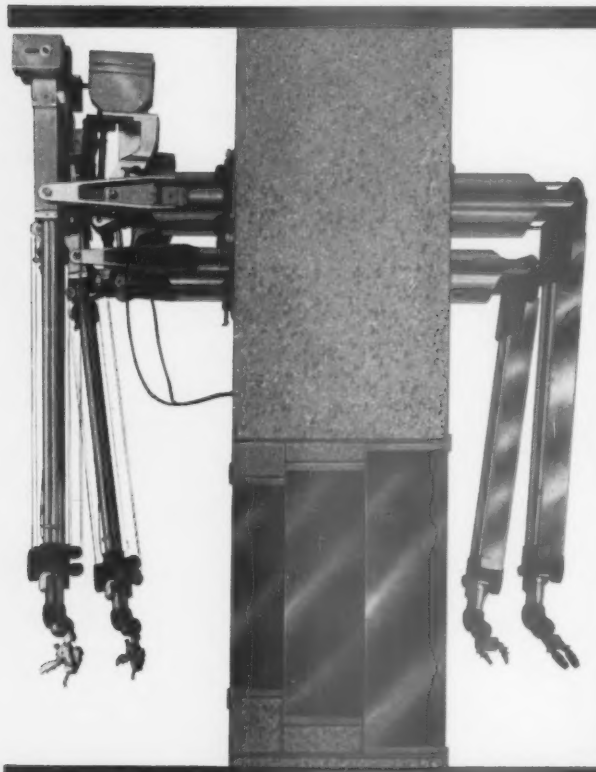
Model D rugged-duty Master-slave Manipulator

CAPABILITIES

Load capacities at tong tips with fully extended boom tube:

- X motion—100 pounds
- Y motion—100 pounds
- Z motion—100 pounds

elevation rotation—50 pound feet
azimuth rotation—50 pound feet
twist-rotation—40 pound feet
gripping force and handling capacity—100 pounds



FEATURES—

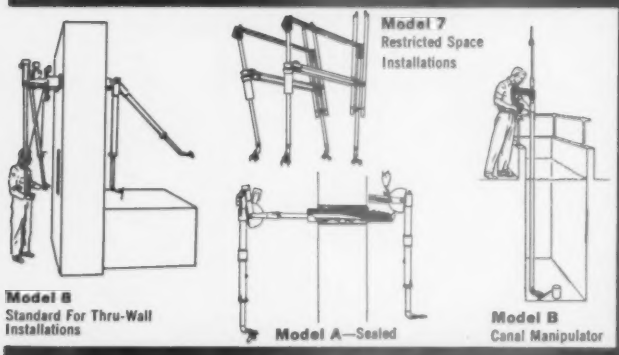
The Model D manipulator is a very rugged modification of the Model 8—a well-known and widely-used manipulator designed and first manufactured by Central Research.

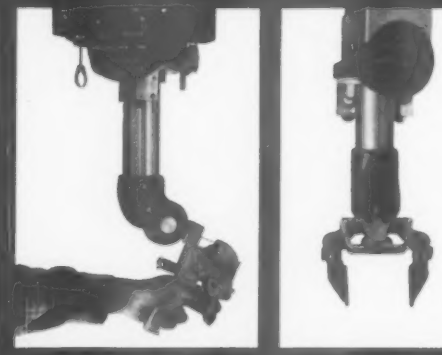
Unique new features of the Model D include: a new wrist joint with sturdy stainless steel gears and a twofold increase in gear ratio; stainless steel boom and counterweight tubes; high-capacity boom-tube rollers; geared-up tape coupled azimuth rotation drive; center-supported pulley shafts; a mechanical, automatically shifting dual-ratio tong-squeeze drive; protected slave-end tapes.

INTERCHANGEABILITY

In general, the Model D is dimensionally interchangeable with a standard Model 8 manipulator with no alteration in mounting arrangement of existing or planned installations. The Model D offers greatly increased reliability and scope in rough-service hot-cell operations with no significant loss of dexterity for performing delicate operations.

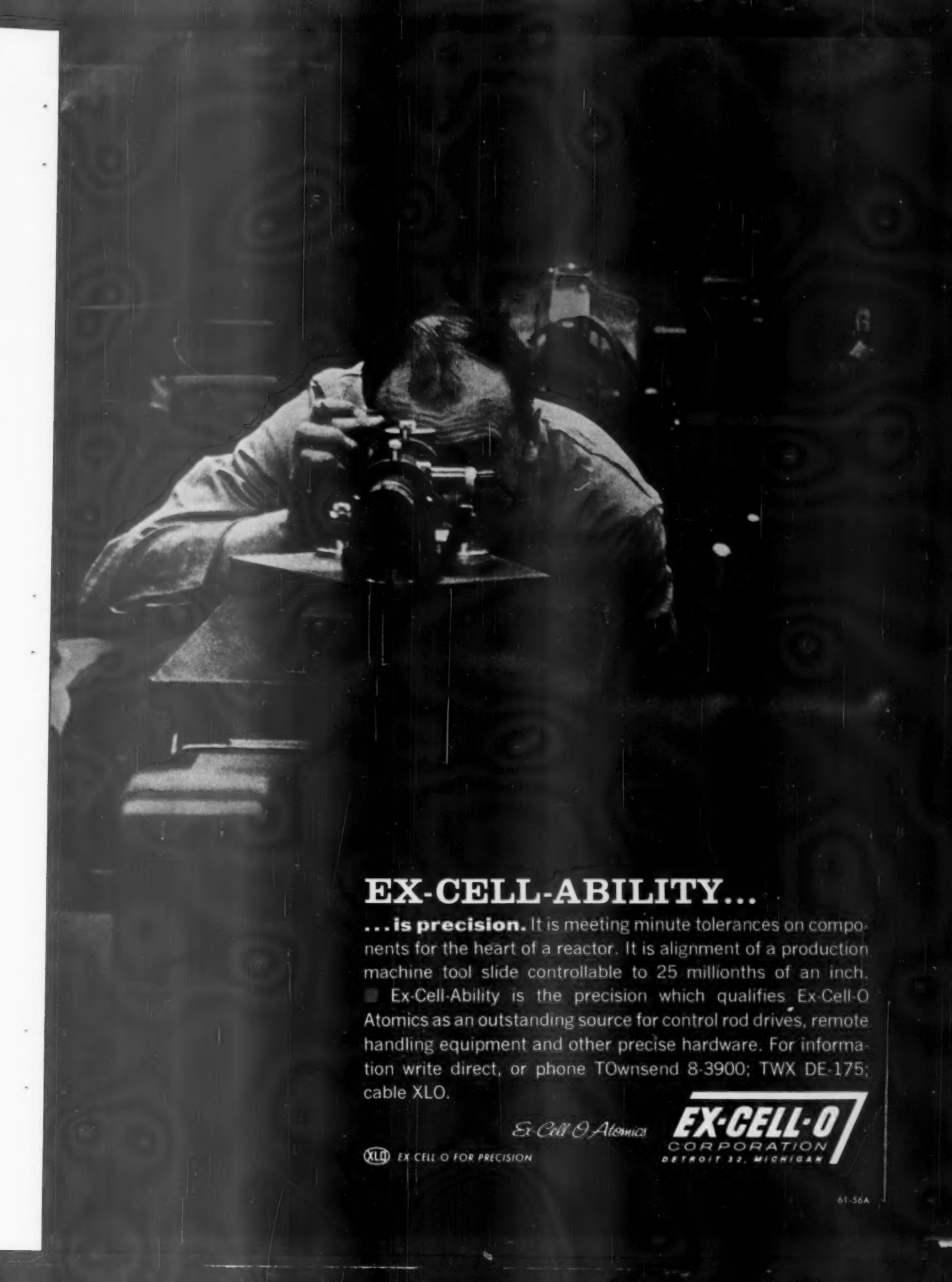
COMPARE—THEN SPECIFY CENTRAL RESEARCH MANIPULATORS FOR EVERY NEED





For further information write:

Central Research
laboratories, inc.
Red Wing, Minnesota, Dept. 116



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...is precision. It is meeting minute tolerances on components for the heart of a reactor. It is alignment of a production machine tool slide controllable to 25 millionths of an inch. Ex-Cell-Ability is the precision which qualifies Ex-Cell-O Atomics as an outstanding source for control rod drives, remote handling equipment and other precise hardware. For information write direct, or phone TOwnsend 8-3900; TWX DE-175; cable XLO.

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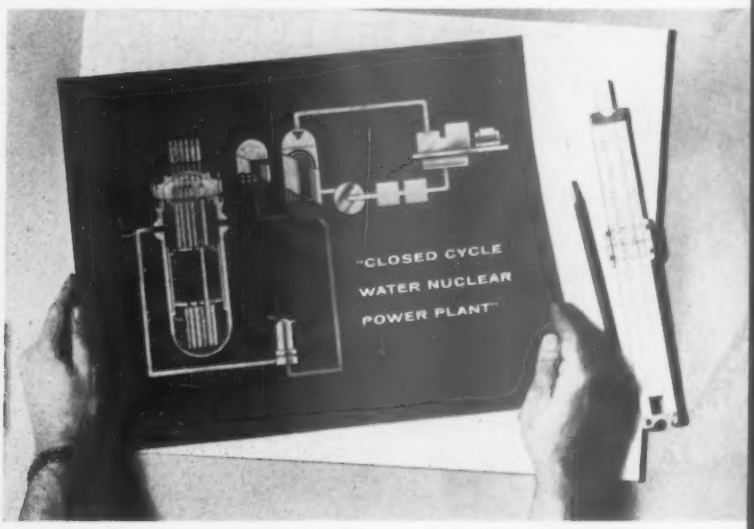
ON THE LINE

Yankee—a Westinghouse achievement of the first order in its continuing effort to bring atomic power to its full commercial capabilities.

ON THE BOARDS

the new 375-Mwe atomic power plant is a giant step forward in the realm of controlled commercial nuclear power. Projects like this offer to professional personnel the opportunity to take part in the design and development of economic nuclear power plants. Career openings for qualified scientists exist in many areas. Some of these areas are listed in the next column.



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Capable of independent work in reactor physics, to direct research and development on advanced reactor concepts, or to perform and direct reactor physics and nuclear design work on cores nearer completion.

SENIOR ENGINEER:

Alloy development on reactor materials and fuels with particular emphasis on control rod and cladding materials. M.S. degree in metallurgy with three years experience in reactor materials.

ENGINEER OR SCIENTIST:

To perform reactor physics calculations on reactor cores which involve problems of the development and application of theoretical methods, founded on basic theory, to technical programs concerned with the design and construction of large power reactors. M.S. degree in physics or nuclear engineering.

SCIENTIST:

Involves the mathematical analysis of problems in reactor physics and engineering with emphasis on the development of digital computer programs or adaptation of existing programs to meet special requirements. B.S. degree in mathematics, physics or engineering with emphasis on applied mathematics and experience in digital computer applications.

MANAGER
PHYSICAL METALLURGY SECTION:

The position requires a man well rounded in the fundamentals of physical metallurgy and with 5 to 10 years experience. Must be experienced with the effects of radiation on metals both fuel bearing and non-fuel bearing. The position will also involve stainless steel and carbon steel alloy development and development in the field of other high temperature metals and ceramics such as graphite, beryllia or other ceramics used in the nuclear industries. A strong foundation of physical chemistry is desirable since there will be problems concerning corrosion. Must be able to assist project design engineers in problems regarding the fatigue, creep and brittle fracture of metals and alloys.

If you qualify for any one of the above positions, write immediately to: Mr. C. S. Southard, Westinghouse Atomic Power Division, P.O. Box 355, Dept. X-84, Pittsburgh 30, Pennsylvania.

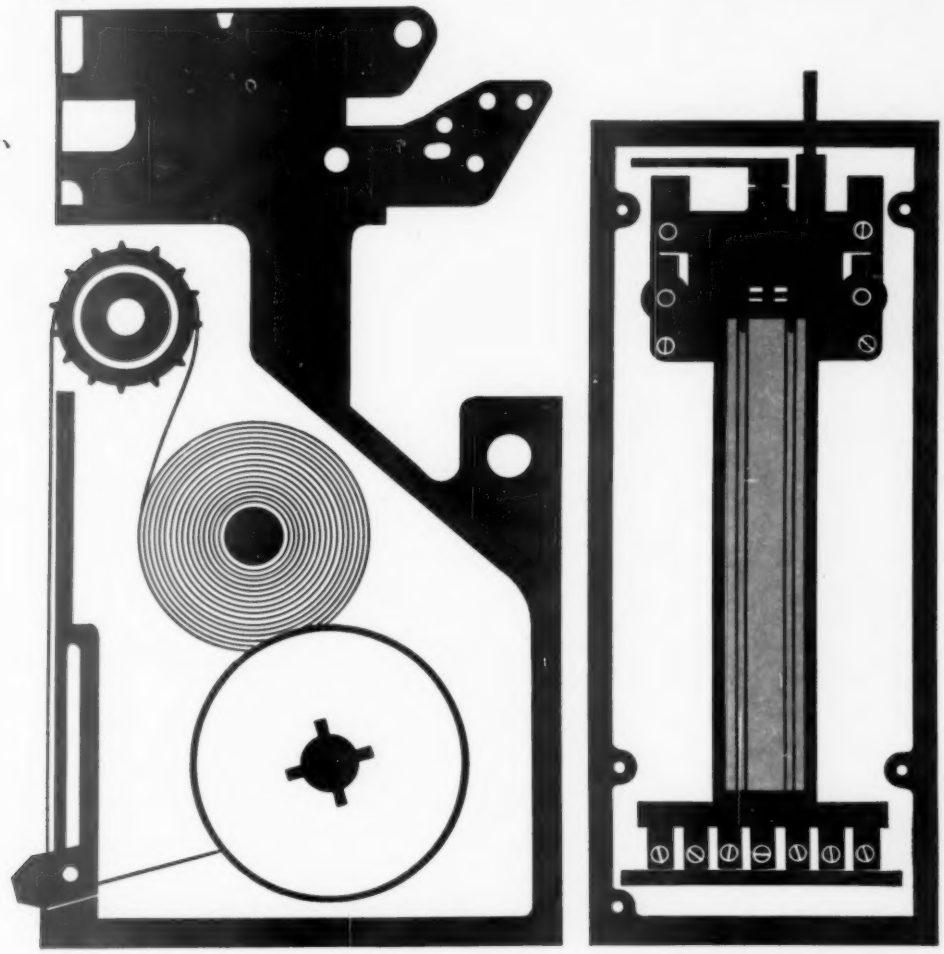
ALL-NEW *ElectroniK 17* POTENTIOMETERS HAVE NO SLIDEWIRE, NO SLIDEWIRE PROBLEMS

Here is a totally new kind of potentiometer with a totally new kind of measuring system. The *STRANDUCER* replaces the slidewire, and sets a new high standard for potentiometer performance. The new *ElectroniK 17* potentiometers have calibrated accuracy of ±0.25%.

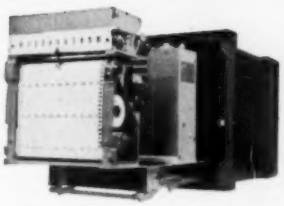
In addition, modular construction makes *ElectroniK 17* instruments easiest of all potentiometers to operate, convert and maintain. Full interchangeability of components cuts service time and spare parts requirements.

You can get *ElectroniK 17* instruments as strip or circular chart recorders or circular scale indicators. You can get electric contact control with up to 8 contacts. All control units are of convenient plug-in type. For all the eye-opening facts about this new class of instruments, call your nearby Honeywell field engineer, or write MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Phila. 44, Pa.—In Canada, Honeywell Controls, Ltd., Toronto 17, Ont.

The unique *STRANDUCER* rebalancing element works on the proven strain gage principle. Both *STRANDUCER* and pen carriage are linked to the potentiometer balancing motor. A change in electrical input causes the balancing motor to change the tension—and electrical resistance—of the *STRANDUCER*, to reposition the instrument pen or pointer. The *STRANDUCER* is unaffected by corrosive atmospheres and has no contactors. It has unusually long life and infinite resolution and is unaffected when the instrument operates in ambient temperatures up to 130° F.



True modular construction saves you time, trouble, money. Three basic modules—case, display and drive—make up the *ElectroniK 17*. The case fits standard 19-inch relay racks. You can remove the door easily and without tools when converting from strip chart to circular chart or circular scale operation. You can pull out the chassis to the service position without tools, and without interrupting operation, or remove it completely. Up to 8 contact control modules can be plugged in for a variety of control possibilities.



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HONEYWELL INTERNATIONAL Sales and Service offices in all principal cities of the world.
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FOXBORO Electronic Consotrol Control Panel for portable nuclear power plant is designed for one-man operation.

reactor control – plant control – radiation monitoring... they're all on this compact Foxboro Electronic Control Panel

SKID-MOUNTED Foxboro Consotrol panel, enclosed in a protective housing, will be "air-lifted" to its Air Force site, 6500 ft. up in the Wyoming mountains.

One skid — that's all the room allowed for control instrumentation on The Martin Company's PM-1 portable nuclear power plant.

The plant — being built for the Air Force under contract to the AEC — will produce both 1000 kilowatts of electrical power and 7 million btu per hour heat for a remote Air Force station high in the Wyoming mountains.

For the PM-1 Reactor, dependable Foxboro Electronic Consotrol* instruments were specified. 100% solid state — no vacuum tubes to replace — instantaneous response. And they're so compact that both nuclear and process control, as well as radiation monitoring, are included on the same operating console.

Compactness — reliability — proven performance — Foxboro Electronic Consotrols are ideal for both nuclear and conventional power plant control systems. Ask your Foxboro Field Engineer to show you the reasons why. Or write for Bulletin 1-17. The Foxboro Company, 626 Neponset Ave., Foxboro, Massachusetts.

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FOXBORO

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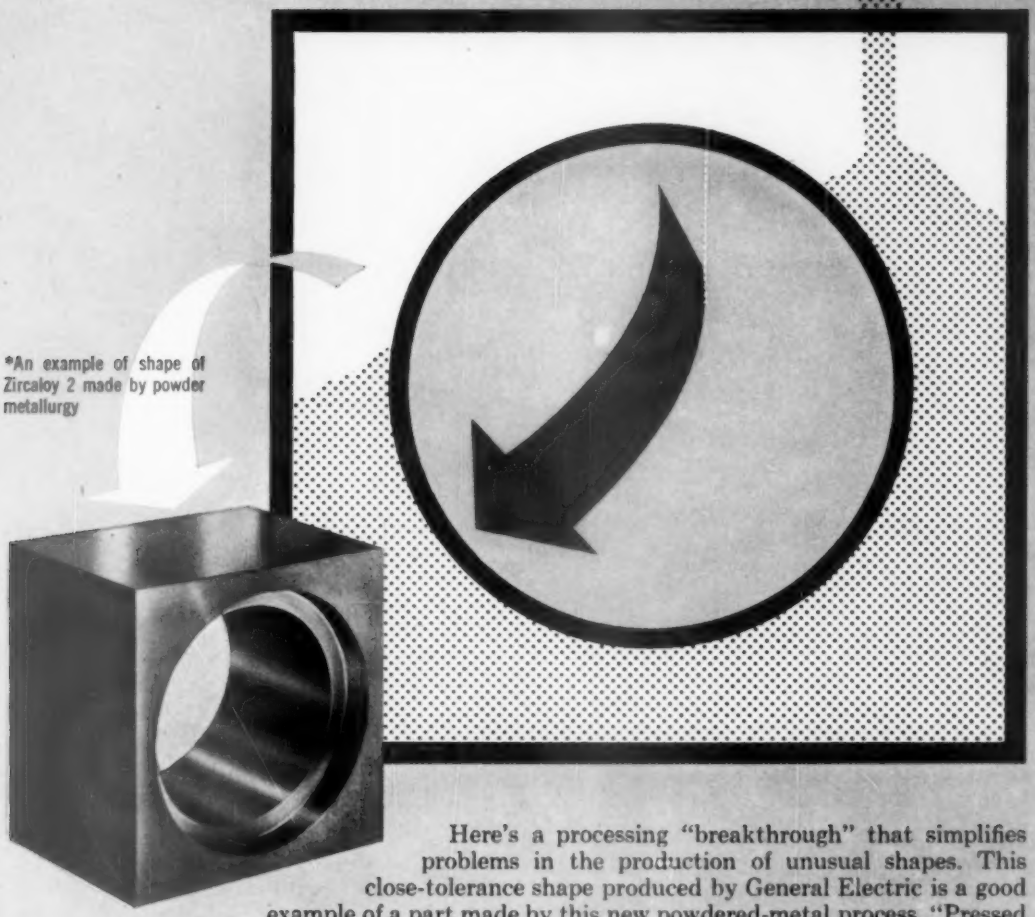
G-E ZIRCALOY 2*

"Pressed-to-shape" metallurgy process slashes machining cost



*An example of shape of Zircaloy 2 made by powder metallurgy

Here's a processing "breakthrough" that simplifies problems in the production of unusual shapes. This close-tolerance shape produced by General Electric is a good example of a part made by this new powdered-metal process. "Pressed to shape" means machining costs are reduced appreciably and expensive metal waste is saved. Low gas content and high density are assured by the process. The corrosion resistance and low-neutron cross-section properties of the metal are highly desirable for nuclear and chemical applications. Zircaloy 2 is now available from General Electric in shapes and billets. Write for full particulars.

METALLURGICAL PRODUCTS DEPARTMENT

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ANOTHER STEP.....

Internal data reduction is another new step by Nuclear Data

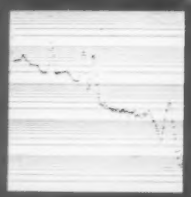
Less obvious at a glance, but even more significant, are the steps taken before automatic digital data reduction could even be applied.

The linearity, stability, measurement resolution, and experiment timing accuracy are better than anything we've seen yet. These are big steps for gamma applications, and vital for high resolution particle analysis.

Simple, dependable punched tape controls for *both* read-in and read-out, precise logarithmic CRT display and pen recording, and typewritten digital read-out are standard features of the model ND 130T Analyzer, and these are all provided by *internal* analyzer circuits.

Here is the finest analyzer in the field.

Write Department 512 for our new 24 page general catalog.



NUCLEAR DATA INC.

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MADISON / WISCONSIN

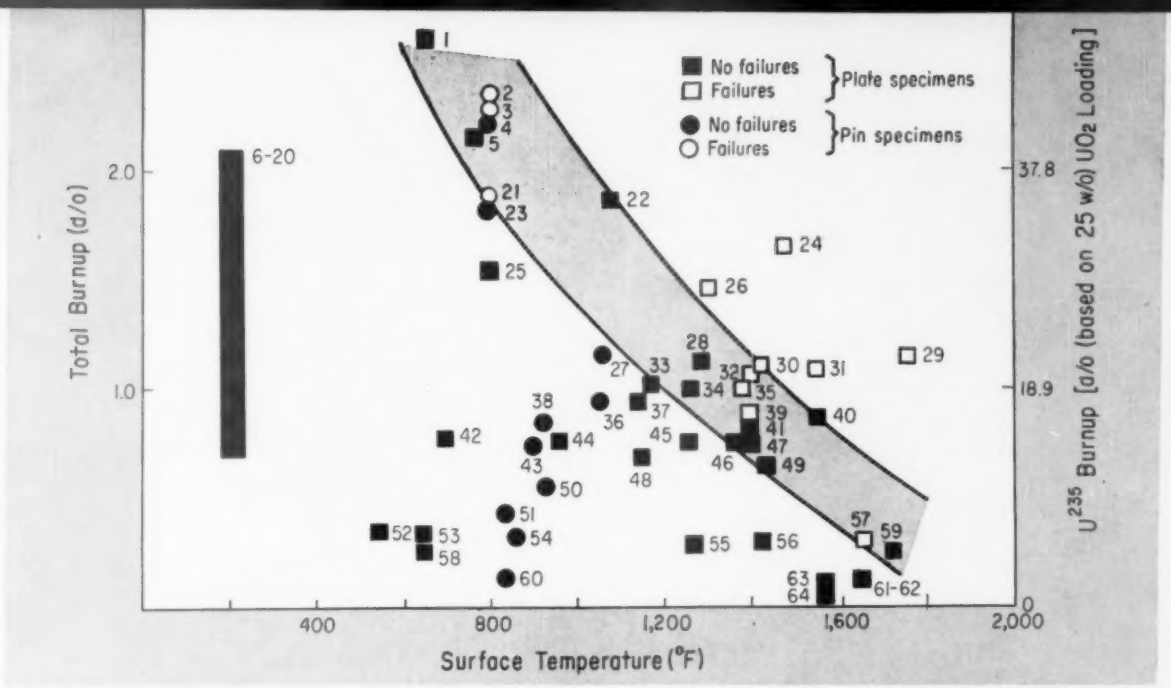

FIG. 1. BURNUP PERFORMANCE of stainless-steel-UO_2 cermet fuel specimens having 18–30 w/o UO_2 (numbers next to data points are specimen numbers shown in Table 1). These data indicate that when a specimen temperature and burnup are below shaded area, a "typical" fuel element will not crack or blister (as seen visually or microscopically) or release radioactive products. Fuels exposed above shaded zone would fail; performance of fuels irradiated within shaded area is difficult to predict

Predicting Burnup of Stainless–UO_2 Cermet Fuels

Although it requires enriched uranium, ss-UO_2 fuel serves well and is predictable in compact power reactors. Fabricators can improve the burnup performance by controlling UO_2 particle "stringering" and other structural defects that cause cracks and blisters

By DONALD L. KELLER, *Battelle Memorial Institute, Columbus, Ohio*

DEVELOPMENT of stainless-steel-UO_2 dispersion fuel elements (consisting of discrete UO_2 particles embedded in a dense stainless-steel matrix that is clad by a thin bonded layer of stainless steel) has progressed steadily during the past seven years. This material is one of the most predictable and versatile fuels for compact power reactors. It has served in a variety of coolants between 500 and 1,700° F. It can be fabricated to nearly any shape and size to which pure stainless steel can be fabricated. These facts warrant serious consideration of ss-UO_2 fuel cermets for use in any reactor environment and at any temperature in which stainless steel itself is serviceable.

After examining its predictable burnup performance, uncertainties and limitations, we can consider ways to further improve the performance of cermet fuels.

Irradiation Data

Figure 1 and Table 1 summarize the results of many capsule irradiations of stainless-steel-UO_2 fuel-element specimens. In Fig. 1 total burnup is expressed as the ratio of U^{235} atoms fissioned to the total number of atoms initially present in the core. Thus data for fuel loadings of 18–30 w/o UO_2 can be presented on a single graph. This simplification has a drawback because a fuel with a small UO_2 loading actually would withstand a higher burnup when burnup is plotted this way (or as the number of fissions per unit volume of core material) than would a fuel with more UO_2. A matrix heavily loaded with UO_2 is not as strong as one with more stainless steel; it also is less able to retain an undamaged metallic

TABLE 1—Irradiation Data on Stainless Steel–UO_2-Dispersion Fuel Specimens*

Specimen characteristics			*Irradiation conditions*						
UO_2 loading (w/o)	*UO_2 particle size (micron)*	*Cladding thickness (mil)*	*Surface temperature (°F)*	*Irradiation time (hr)*	*Burnup U^{235}*	*(a/o) total†*	*Results*	*Identification in Fig. 1*	*Ref*
PLATES									
Type-304ss matrix; Type-304Lss cladding									
17.92	—	5	190	—	52.5	1.93	No failures	6–20	*13*
17.92	—	5	190	—	40.0	1.48	"	6–20	"
17.92	—	5	190	—	45.4	1.68	"	6–20	"
17.92	—	5	190	—	10.5	0.39	"	6–20	"
17.92	—	5	190	—	40.0	1.48	"	6–20	"
17.92	—	5	190	—	53.5	1.98	"	6–20	"
17.92	—	5	190	—	51.2	1.89	"	6–20	"
17.92	—	5	190	—	13.1	0.48	"	6–20	"
17.92	—	5	190	—	56.9	2.10	"	6–20	"
17.92	—	5	190	—	53.1	1.96	"	6–20	"
17.92	—	5	190	—	48.1	1.78	"	6–20	"
17.92	—	5	190	—	29.2	1.08	"	6–20	"
18.75	—	8	212	400	16.0	0.7	"	6–20	"
22.18	—	10	212	400	18.0	0.9	"	6–20	"
26.89	—	12	212	400	12.0	0.8	"	6–20	"
Fe, 18Cr, 14Ni, 2.5Mo(elemental) matrix; Type-318ss cladding									
25	75–150	6	1,725	32.7	5.4	0.20	"	59	*4*
25	75–150	6	1,430	47.5	12.7	0.67	"	49	"
25	75–150	6	1,550	47.5	16.6	0.88	"	40	"
25	75–150	6	1,400	85.2	20.4	1.08	Large blister	32	"
25	75–150	6	1,417	85.2	20.7	1.10	Small blister	30	"
25	75–150	6	1,650	52.7	2.2	0.12	No failures	61	"
25	75–150	6	1,650	52.7	2.6	0.14	"	62	"
30	75–150	6	1,655	32.7	4.9	0.32	Small blister	57	"
30	75–150	6	1,533	47.5	17.5	1.15	"	31	"
30	75–150	6	1,395	47.5	15.6	1.04	Ruptured	35	"
30	75–150	6	1,475	85.2	25.1	1.66	"	24	"
30	75–150	6	1,300	85.2	22.2	1.47	"	26	"
Fe, 18Cr, 9Ni(elemental) matrix; Type-347ss cladding									
30	>44	6	550	610	5.3	0.35	8 pcs; 0 failed	52	*13*
30	>44	4	650	425	4.4	0.29	"	58	"
30	>44	4	650	412	5.4	0.36	"	53	"
30	>44	4	700	1,038	12.1	0.79	"	42	"
30	>44	4	650	2,550	39.7	2.6	"	1	"
30	>44	4	800	—	23.5	1.54	"	25	"
30	>44	4	766	4,015	33.3	2.17	"	5	"
30	>44	4	1,080	2,415	28.6	1.86	"	22	"
30	>44	4	1,400	1,889	12.9	0.84	8 pcs; 2 cracked	39, 41	"
30	>44	4	1,765	880	17.4	1.14	8 pcs; all failed	29	"
Type-310ss matrix and cladding									
30	>105	5	1,260	370	4.6	0.30	2 pcs; 0 failed	55	"
30	>105	5	1,420	420	4.8	0.31	"	56	"
30	>105	5	1,560	370	1.8	0.12	"	63	"
30	>44	4	1,550	288	1.1	0.09	"	64	"
Fe, 23Cr, 17Ni(elemental) matrix; Type-318ss cladding									
30	>44	4	1,290	815	17	1.12	No failures	28	"
Fe, 18Cr, 14Ni, 2.5Mo(elemental) matrix; Type-318ss cladding									
30	75–150	6	1,240	2,250	15.1	1.00	No failures	34	*14*
30	75–150	6	1,190	2,250	15.4	1.02	"	33	"
30	75–150	6	1,130	2,250	14.2	0.94	"	37	"
30	75–150	6	970	2,250	12.0	0.79	"	44	"
30	75–150	6	1,360	1,474	11.8	0.78	"	46	"
30	75–150	6	1,400	1,474	11.8	0.78	"	47	"
30	75–150	6	1,270	1,474	11.5	0.76	"	45	"
30	75–150	6	1,140	1,474	10.4	0.69	"	48	"
PINS									
Type-347ss matrix and cladding									
23	—	10	860	790	6.7	0.33	No failures	54	*13*
24	—	10	930	—	16	0.82	"	38	"
24	—	10	842	—	3	0.15	"	60	"
24	—	10	842	—	8.2	0.42	"	51	"
30	—	10	930	1,000	8.9	0.58	"	50	"
Fe, 18Cr, 12Ni(elemental) matrix; Type-304ss cladding									
24.5	—	10	1,060	2,790	18	0.94	No failures	36	*13*
28.5	—	10	1,060	2,790	18	1.13	"	27	"
28.5	—	10	900	—	12	0.75	"	43	"
30	44–74	10‡	800	1,662	28	1.85	2 pcs; 1 failed	21, 23	"
30	44–74	10	800	2,520	34	2.24	"	3, 4	"
30	44–74	10	800	3,310	35	2.31	Ruptured	2	"

* This table includes data only from experiments in which temperatures were carefully monitored and burnup was measured either radiochemically or isotopically.

† The conversion to a/o burnup is based on a U enrichment of 93% in all cases.

‡ Type-347ss cladding.

matrix during irradiation. Fortunately, all data points within the shaded area in Fig. 1 are from fuel specimens of similar UO_2 loadings (25–30 w/o). So the boundaries of this critical region are realistic for elements of this particular loading range and are conservative for elements of lower UO_2 loadings.

Since it is common practice to express burnup in dispersion fuels as a percentage of the U^{235} atoms that are destroyed, this is done in Fig. 1 for a fuel loading of 25 w/o. Figure 2 shows a conversion from w/o UO_2 to a/o U^{235} in ss-UO_2 bodies. Consider an example of how this can be used with Fig. 1. At a surface temperature of 1,000° F, Fig. 1 indicates the fuel will fail at a total burnup of about 1.4 a/o. From Fig. 2 we learn that a material with 30 w/o UO_2 contains 6.6 a/o U^{235} atoms; thus 1.4 a/o burnup can be expressed as 1.4/6.6 or 21.2% of the U^{235} atoms. At the same surface temperature a material with only 15 w/o UO_2 could sustain a burnup of 42.2% of the U^{235}; this burnup estimate is probably conservative because of the lower UO_2 loading of the fuel.

Damage Mechanisms

If we are to operate a stainless-steel-UO_2 dispersion fuel in or above the shaded area in Fig. 1, we must consider carefully how burnup performance is affected by (a) UO_2 particle size and loading, (b) burnup rate and (c) structural imperfections. We also need to learn ways to prevent causing imperfections in the fabrication process.

Many theories to describe the performance of dispersion fuels have been considered (*1*). It will be helpful to review the ideas particularly related to ss-UO_2 fuel elements and to consider recent concepts and personal observations.

Growth of UO_2. The stainless-steel matrix and cladding will resist any tendency of the UO_2 fuel particles to increase in size during irradiation. Such increases could develop stresses within an element sufficient to cause failure. There are two possible modes (*1*) of UO_2 growth: (a) normal growth caused by accumulation of fission products in the lattice (with the normal growth rate R_N being the rate of volume increase per unit burnup) and (b) abnormal growth caused by the thermal diffusion and agglomeration of the fission gases that produce internal pores

containing gas under high pressure (abnormal-growth rate = R_A). It follows that the rate of growth of the dispersion core R_T is

$$R_T = V_f(R_N + R_A) \qquad (1)$$

(V_f is the volume fraction of UO_2 in the core). This relationship can be developed further to show the total growth of a clad element as

$$A_T = BV_CV_f(R_N + R_A) \qquad (2)$$

where V_C is the volume fraction of the core to the total element, and B is burnup. In typical irradiation samples V_f = 0.15–0.25 and V_C = 0.4–0.8. Thus it is apparent from Eq. 2 that the total growth of the UO_2 particles should exceed the total specimen growth by a factor of 5 to 15, assuming no abnormal failures or blistering within the matrix. Thus, because of the increased sensitivity of measurements, we should measure the growth of the fuel particles themselves as well as the growth of the over-all fuel-element when we are trying to evaluate various types of UO_2 particles or dispersants.

By estimating the distribution of all possible oxides formed from fission products and residual oxygen and then calculating their molecular volume, one can predict a normal growth rate for UO_2 at high burnups of R_N = 1.2 (*2*).

Abnormal growth of UO_2 particles occurs by the formation of large internal pores; it occurs most often in specimens irradiated to high burnup. The fact that the effect is more pronounced at high temperatures supports the concept of gas agglomeration and plastic deformation of the UO_2. However, the pores have appeared in UO_2 irradiated at temperatures no higher than 400° C but to very high burnups. Since UO_2 is not likely to deform plastically at these temperatures, this phenomenon might be related more to the presence of larger amounts of fission-product impurities than we had thought previously.

Fission-fragment escape. The average recoil range of fission fragments in UO_2 is 9.4 microns (*3*). The fraction F that escape from a spherical UO_2 particle is

$$F = \frac{3}{4}\frac{\lambda}{a} - \frac{1}{16}\left(\frac{\lambda}{a}\right)^3 \qquad (3)$$

where a is the particle radius and λ is the fission-fragment range in the UO_2 particle (*3*); Fig. 3 shows this relationship. Thus the disadvantage of fine UO_2 particles is that the fission gas that escapes the UO_2 will collect in the stainless-steel matrix, readily agglomerate in the badly damaged region adjacent to the UO_2 particles, and in time build up sufficient pressure to rupture the core. This type of failure is resisted primarily by the stainless-steel matrix, whose integrity and strength are determined largely by the fabrication process.

Damage of matrix. To resist most effectively the internal gas pressure created during irradiation, a continuous skeleton of stainless-steel matrix must be free of the fission fragments escaping the UO_2. The relationship among the distance d between UO_2 particles, the UO_2-particle diameter D and the volume fraction V_f of UO_2 for a cubic array of spherical particles is

$$d = D\left[\left(\frac{\pi}{6V_f}\right)^{1/3} - 1\right] \qquad (4)$$

This relation is plotted in Fig. 4, with twice the fission-fragment range in stainless steel indicated by a horizontal line. All conditions below this line give a continuously damaged stainless-steel matrix connecting the UO_2 particles.

Burnup rate. A creep theory has been developed to relate the effects of temperature, irradiation time and burnup on fuel-element life (*4*). The creep theory considers the relative effect of varying temperature and time rather than being a complete failure theory based on a detailed mathematical model of the fuel structure. Thus criteria have been defined to estimate relative severity of irradiation results under different test conditions but on identical specimens.

From tests that yielded both failed and unfailed specimens, this theory was used to estimate various combinations of the test parameters that would produce a failed specimen. For example, in the range 1,200–1,400° F, increasing the burnup rate ten times (as in accelerated irradiation tests) should nearly double the burnup allowable before the first signs of fuel-element failure appear.

Differences in UO_2 particle sizes, burnup rates or temperature variations could explain the contradictory nature of some of the data points in the shaded region of Fig. 1. Other variations in burnup performance could be caused by the fuel-element configuration (*5*) (for example, pins vs plates) and the

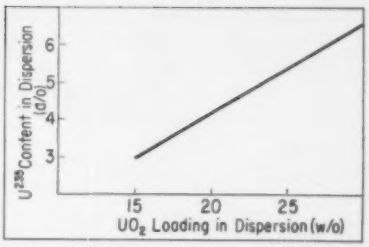

FIG. 2. Relationship between U^{235} content and UO_2 loading in a 93% enriched ss-UO_2 dispersion-type fuel material

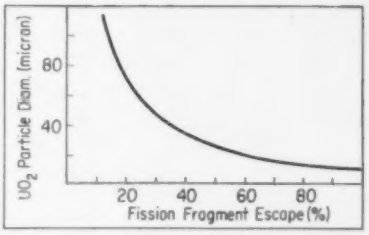

FIG. 3. Fission fragments escape from small UO_2 particles more easily than from large particles—and thus damage the stainless-steel matrix more

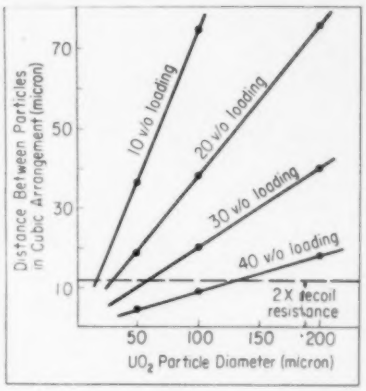

FIG. 4. Matrix of stainless steel between UO_2 particles is damaged more by fission fragments if UO_2 particles and distance between them are small

wide differences in the mechanical properties of what might appear to be identical specimens (same cladding and core thickness, same UO_2 loading, etc.) as a result of variations in the fabrication procedures.

Stringering

As Tables 1 and 2 show, flat-plate fuel elements (made by the hot reduction of a stainless-steel-UO_2 core compact enclosed in a cladding jacket of stainless steel) have been used and tested most extensively. From the

standpoint of irradiation resistance of plates, a key factor that arises during fabrication is the extent of fracturing of the UO_2 fuel particles and the alignment of these particles in the direction of rolling. This stringering involves the fragmentation and segregation of the UO_2 particles into regions of high and low fuel concentration (*6*, *7*). This results in heavily damaged zones during irradiation. The detrimental effects of stringering can be described by the results of transverse tensile tests in which the core strength is measured normal to the stringers and the major cladding surfaces. Such data taken at room temperature show that the transverse tensile strength of fuel elements containing 30 w/o UO_2 can vary by a factor of 25 (~1,000 to 25,000 psi), depending on the fabrication method (*8*). In view of this the discrepancies shown in Fig. 1 are not surprising. Thus we believe that elimination of UO_2 stringering is an important way to lengthen the irradiation life of cermet fuel elements.

Spherical particles. One technique being used to reduce stringering involves only the substitution of a nearly spherical, dense, strong UO_2 particle for the more conventional high-fired or hydrothermal UO_2 particle. The spherical particles are less likely to align themselves during fabrication and also show less tendency to fracture, thus transverse tensile strength is higher (*8*). Irradiation tests are in progress to demonstrate the real worth of these improvements in terms of the ability to achieve higher burnups.

Other variables. The stringering effects of several variables involved in the fabrication of flat plates are fairly well known (*6*, *7*). High rolling temperatures, large reductions per pass, fine stainless-steel powder, and dense core compacts all favor less stringering of the oxide.

Less rolling. The less a plate is reduced in thickness during rolling the less stringering results. The problem is to determine how much rolling is needed to bond the fuel-plate components (core, cladding, frame) metallurgically. Specifications often require large (~10 to 1 reductions in thickness). But our data indicate that only slight reductions are needed to bond core and cladding if the mating surfaces are kept very clean during fabrication (all specimens fractured across the core rather than at the core-clad interface—thus demonstrating good bonding). Although the core and cladding bond during reductions as low as 1.1 to 1, to insure consistently reliable bonding of the core and frame and complete densification of the core, reductions of at least 3.5 or 4 to 1 are needed. At these small reductions the extent of stringering during rolling is significantly less than after reductions of 10 to 1. An added dividend results from the shorter heating times needed for smaller reductions during hot rolling: less boron burnable poison is lost by diffusion from boron-stainless-steel alloys.

Total reduction ratio	*Transverse ultimate tensile strength (psi)*
1.1 to 1	22,800
1.2 to 1	23,700
1.6 to 1	29,500
1.8 to 1	29,700

Other fabrication techniques. Pressure bonding (*9*), slip casting (*10*), cold extrusion (*11*), and powder rolling (*12*), or combinations of these cause less UO_2 stringering than does rolling because they involve less metal flow during fabrication. These processes will assume more important roles in future fabrication of ss-UO_2 dispersion fuel elements if they do indeed improve irradiation life.

TABLE 2—Reactors Using Stainless-Steel–UO_2 Dispersion Fuel Elements (*15*)*

Reactor	*Date critical*	*UO_2 fuel loading (w/o)*	*Fuel shape*	*Coolant*
Spert-1	7/11/55	19	Plates	Water
SM-1 (APPR-1)	4/57	24	Plates	Water
VBWR, Core 1	8/57–10/59	23–29	Plates	Water
OMRE	9/57	25	Plates	Terphenyl
Spert-3	12/58	19	Plates	Water
GCRE-1, Core 1	2/60–9/60	30	Plates formed into tubes	N_2 + 0.5% O_2
PM-2A	10/2/60	24	Plates	Water
SM-1A(APPR-1A)	(61)	24	Plates	Water
PM-1	(61)	29	Tubes	Water
EOR	(1/62)	17	Plates	Santowax-R
PM-3A	(2/62)	29	Tubes	Water
Sioux Falls Superheater	(62)	20.4	Tubes	Steam
HTRE-1†	1/56–12/56	40,42	Cylinders	Air
HTRE-2†	2/57	40,42	Cylinders	Air
HTRE-3†	10/58	40,42	Cylinders	Air

* In addition to the broad development studies supporting reactor systems listed here, extensive development work was done on ss-UO_2 as an alternate fuel material for the S1G reactor (*1*) and as a reference fuel element for the Supercritical Water Reactor (*16*).

† Metal matrix was a nickel-chromium alloy similar enough to stainless steel to warrant inclusion in this list.

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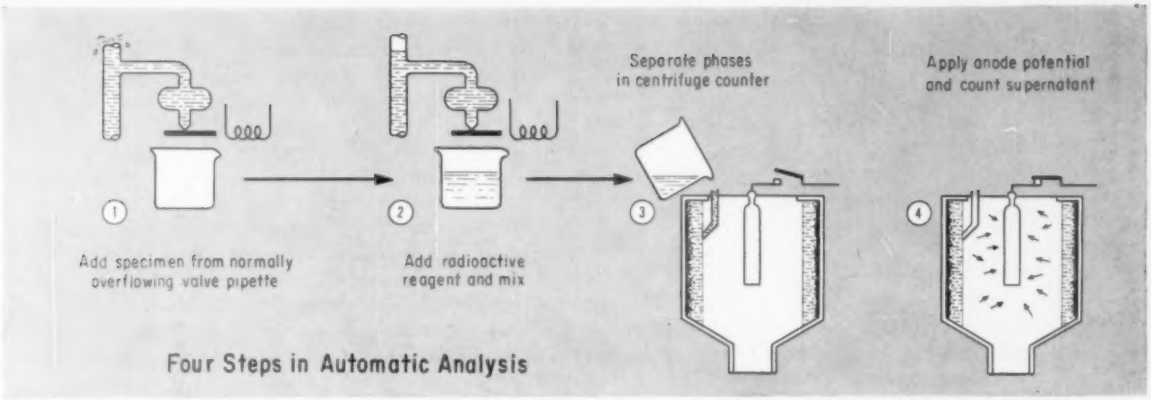

FIG. 1. AUTOMATIC BOILER WATER ANALYSIS uses four automatically programmed steps to measure PO_4^{---} concentration. Total cycle requires only 10 min. Twice-a-day standardization requires third valve pipette and 10-ppm solution of PO_4^{---}

Radiometric Chemistry for Automatic Process Control

Radiometric techniques, properly developed, are capable of greater accuracy than most users realize. Since they recognize most elements, they are appropriate for many automatic analyses

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RADIOMETRIC CHEMISTRY is only beginning to be recognized for the potential value that it has in rapid analysis, automatic analysis and automatic process control. The slowness of this recognition is probably caused mainly by a lack of understanding of how accurately radiometric methods can be applied. But there are many ways in which a chemical process parameter can be rapidly and accurately measured by counting. In general one makes use of a chemical property such as the ability of a constituent to combine with a radioactive reagent or reduce the specific activity of a part of a mixture. Such methods are referred to as "radiometric chemical analysis."

We can classify radiometric methods into four groups according to their applications: isotope dilution, extent-of-reaction analysis, end-of-reaction analysis and analysis evaluation. When properly developed they have many advantages. Perhaps the most conspicuous one is that a radiometric measurement produces an electrical signal that is readily used as an input for automatic equipment. Other advantages are that these methods are simple, cheap, widely applicable, free of interference, linear in response and accurate. In one recent application we have used an extent-of-reaction technique to develop a completely automatic boiler-water analyzer (Fig. 1). In connection with our development we have made some interesting counters that are particularly appropriate for automatic analysis.

Accuracy

Because of the way in which radiotracing is usually applied, it is grossly unprecise compared to the usual measurement in an analysis. It has been pointed out that this is largely due to measuring the wrong fraction (*1*). For example, two variations of a good precipitation procedure can seem to be identical when the precipitate is counted but differ by a factor of ten or more if one assays the filtrate. Counting precision is the same in both methods, ~1%, but the percentage variation in the filtrate would be so large that this relatively large lack of precision would not matter.

Suppose that we precipitate 99% of a radiotracer by adding a measured amount of reagent in slight excess. If we count the precipitate with 1% precision, we will have 1% precision in the experiment. If on the other hand we count the filtrate with 1% precision, our over-all accuracy will be 1% of 1%, which is 0.01%.

The point is, of course, that radiometry, because it has great sensitivity, can be used to measure residual amounts of material that one could not weigh. Thus it becomes practical to use the inherently greater accuracy of determining residual values to

compensate for the lack of precision of the radiometric step.

Isotope Dilution

For every element in the periodic table and every chemical entity that can be synthesized there is an isotope-dilution method. In essence the method consists of four steps: (1) determining the ratio of a given nuclide to the other nuclides in a measured amount of a compound, (2) mixing with an unknown amount of the same compound deficient in the nuclide, (3) withdrawing a sample of the mixture and determining the concentration of the tracer nuclide and (4) computing the amount of unknown from the dilution factor (*2*).

The method is particularly appreciated by biochemists and medical specialists. They like the simplicity of isotope dilution more than the analytical chemist, who works with more easily controlled systems.

The power of the method is demonstrated best when the chemical fraction of interest is dispersed in low concentration. In such situations quantitative separation is a formidable task, but frequently isolation of some pure product is rather simple. Even when quantitative recovery is easy, however, the method may effect a saving in time. In electrogravimetric methods, in particular, one may save time by electrolyzing only long enough to get a weighable sample. The same is true for slow-forming precipitates.

The use of isotope dilution in completely automatic process control is a few years away; considerable engineering remains to be done. But the technology of automatic sample measurement is further advanced in radiometric instrumentation than in any other type of quantitative instrumentation. Surely, at any time now, isotope dilution will be applied to process control simply because it is possible to measure automatically in an unattended laboratory overnight samples that have been processed during the working day.

Extent of Reaction

The essence of a radiometric method is the use of a reagent with a radioactivity that has been standardized in terms of chemical equivalence. In extent-of-reaction analysis the amount consumed in a reaction is determined by measuring radioactivity alone. To do this one must isolate the reaction product in space or phase so that one gets a variation in measured radioactivity proportional to the amount of reaction product formed. It is not necessary that the separation be quantitative for the analysis to work; it is only necessary that the fractional separation be constant from specimen to specimen.

The proportionality factor that relates the change of radioactivity to an amount of product depends on the degree of separation and affects the sensitivity. Usually it is a constant or can easily be made one. When it is not, the equation departs from linearity. The required correction must be evaluated from independent observations.

This then is a powerful method that can be applied to analysis systems using many different kinds of separation steps, either partial or complete. Filtering, centrifugation, extraction into immiscible solvent, dialysis and, under some conditions, ion-exchange-resin treatment can all be adapted to this form of analysis.

Usefulness. The method has been applied very little to date, and except in our own laboratories (*3*) it has not been applied at all in systems using incomplete separation. The usual way of applying the principle is by measuring the reaction product directly. Thus sugars and polysaccharides have been assayed by using excess C^{14}-labeled sodium cyanide to form radioactive cyanohydrin. After driving off the excess cyanide as a gas the reaction product is counted (*4*). Thallium iodide has been precipitated with standard radioactive iodide and the precipitate collected and counted (*5*). Labile hydrogen atoms in organic compounds have been measured by exchange reaction with tritiated isopropyl alcohol which was removed by evaporation so that the reaction product could be counted (*6*).

Another typical extent-of-reaction analysis is one in which the analyst uses standardized radioactive iodide in excess to reduce the unknown in the form of nonradioactive iodate. The iodine formed is extracted into carbon tetrachloride and counted (*7*).

In spite of the minimal use of the principle at present the potential of the method is equal to that of isotope-dilution analysis. First of all, it can readily be adapted to continuous automatic process control by substitution of a radioactive reagent for the one presently in use. This permits the use of usual gravimetric and volumetric procedures but results in an electrical signal as output. For manual analysis it is quite convenient since in most cases liquid samples can be used and separation techniques can be quite casually treated.

Secondly radiometric extent-of-reaction analysis is inherently more accurate than isotope dilution, which is limited by the accuracy of the radiometric step, usually ~1%. Increasing the accuracy of a single extent-of-reaction analysis to a maximum requires only that the excess of reagent be as slight as possible. Then the over-all fractional error is the product of the fractional excess of reagent and the fractional error in counting the excess. If, for example, the excess of reagent is 10% and the counting error is 5%, the over-all error is only 0.5%. Since it is really quite easy to reduce the experimental counting error to less than 2%, accuracies of 0.2% can be achieved routinely.

Characteristics of Extent-of-Reaction Analyses

Ion sought	*Reagent*	*Radioactive indicator*	*Phase separation*	*Concentrations investigated (ppm)*	*Lower limit sensitivity (ppm)*
Cl^-	$AgNO_3$	Ag^{110}	AgCl	0–250	0.4
I^-	$AgNO_3$	Ag^{110}	AgI	0–60	0.6
CrO_4^{--}	$AgNO_3$	Ag^{110}	Ag_2CrO_4	0–2,000	12.5
CN^-	$AgNO_3$	Ag^{110}	AgCN	0–200	2
Cl^-	$Hg_2(NO_3)_2$	Hg^{203}	Hg_2Cl_2	0–12.5	0.8
Ba^{++}	Na_2SO_4	$S^{35}O_4$	$BaSO_4$	0–400	5
SO_4^{--}	$BaCl_2$	$S^{35}O_4$	$BaSO_4$	37–300	
Pb^{++}	Na_2SO_4	$S^{35}O_4$	$PbSO_4$	75–600	
F^-	$CaCl_2$	Ca^{45}	CaF_2	0–1,000	50

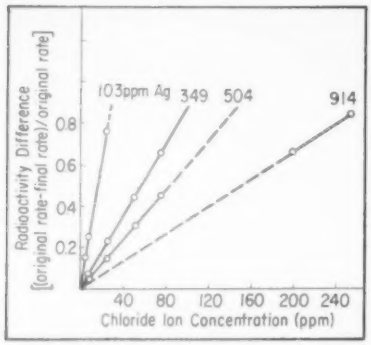

FIG. 2. EXTENT-OF-REACTION analysis produces linear response as long as separation is constant from specimen to specimen

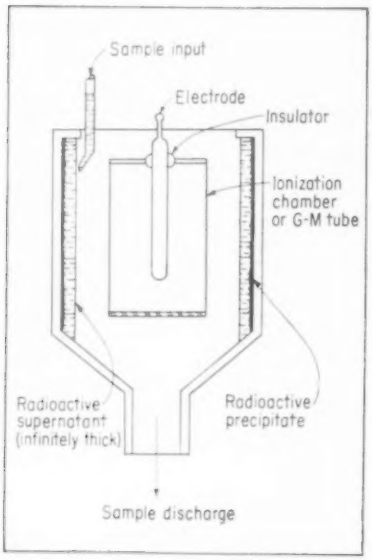

FIG. 3. CENTRIFUGE COUNTER causes precipitate to settle so that counter responds only to radiation from supernatant

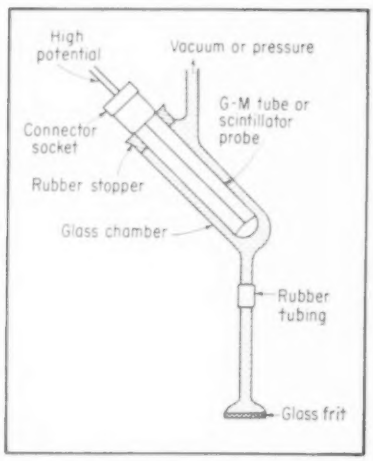

FIG. 4. JACKETED COUNTER sucks liquid to be assayed into volume around G-M tube to separate two-phase system

A third advantage is relative freedom of this type of assay from interference of a physical nature. The method is unaffected by occluded impurities in the precipitate and color and extraneous turbidity in solutions.

In our laboratories we have tried this type of analysis on many systems and so far we have found that all of the systems we have studied follow the linear behavior we expect. The table shows the characteristics of many analyses including the ions we were looking for, the reagents we used and the sensitivities we achieved. In addition to the ions listed in the table, Br^-, PO_4^{---}, Ba^{++} and Ni^{++} have given satisfactory indications.

As shown in Fig. 2, representative results show a linear response. If the separation factor is not constant over the range of interest, one must apply corrections, but this is not difficult. Figure 2 also shows that selection of the proper reagent concentration is helpful in increasing accuracy.

End-Point Analysis

The third way in which analysts are making use of radiotracers is in end-of-reaction or end-point analysis. In this method the radioactivity measurement is not the only or even the major quantitative step. In the simplest form a radioactive reagent is added stepwise until radioactivity appears in a different phase from that in which the reaction product is found (*8*). Alternatively the unknown is added stepwise to the radioactive reagent in an initially homogeneous phase to form a multiphase system, and the diminution of activity in the first phase is plotted and extrapolated to an end point (*9*). Still another way is to titrate in a medium containing radioactive ions that are not involved in the titration reaction. If a new phase, such as a precipitate, is being formed, the disappearance of the unknown ion at the end point may permit the radioactive ion to be strongly adsorbed on the precipitate and consequently the radioactivity of the liquid phase will be abruptly reduced in activity, signaling the end point (*10*). Some of the ions that have been determined in these ways are fluoride and sulfate representing anions, and silver, thallium, cadmium and zinc among the cations (*11*).

The method at present is not markedly more convenient than similar volumetric analyses—especially for those ions for which visual or electrical end points can be used. It does hold promise for process control, however, since the appearance of radioactivity or a rise in radioactivity is a very desirable signal. We feel that this is one of the easiest of all schemes to get into application on continuous process control. Certainly within the next few years we can expect to see such instrumentation in operation in an actual plant process. In laboratories it will probably see slow growth in exceptional situations in which interferences arise with other indicators.

Analysis Evaluation

The final class of analytical uses is that of evaluation of old or new analytical procedures and development of new ones. Radionuclides are employed as tracers rather than reagents to facilitate study of losses or occlusion.

An example of evaluating old analysis methods is determination of the effect of iron on the assay of tin in brass alloys. It was possible to evaluate the accuracy of the iron-free process, the extent of coprecipitation when iron was present and the extent to which the tin was held back by iron (*12*). In developing new analyses a typical example is the chromatographic separation of alkali ions. The nuclides Na^{22}, K^{42}, Rb^{86} and Cs^{137} can be followed by counting, which simplifies the development enormously (*13*).

Very involved analyses may seem to work very well, but the analyst may wonder whether his results are artificial. Radionuclides frequently settle this question. In fact this scheme of study seems so reasonable and easy that one would expect that its use would be nearly universal in developing new methods of analysis.

Automatic Analyzer

Based on radiometric extent-of-reaction analysis is an automatic boiler-water analyzer that measures and records the amount of PO_4^{---} ion in the range 0–50 ppm. The four steps of this operation are as follows (Fig. 1):

1. Divert a small standard volume of the process stream
2. Add a standardized radioactive reagent ($Ca^{45}Cl_2$) in slight excess
3. Separate the phases by centrifugation
4. Count the supernatant.

On a microswitch command a valve

pipette, kept full by a stream that normally overflows at ~2 cm³/min, dumps its contents into a reaction vessel. The radioactive reagent is added similarly except that on signal its valve pipette fills to an electrically controlled level and does not overflow. The two reactants are stirred in the vessel for a few minutes until a signal causes the vessel to empty. The resulting slurry then flows into a centrifuge counter.

In the counter the slurry is directed onto the wall of a cylinder spinning at 3,450 rpm (Fig. 3). After about a half minute of centrifugation the anode potential is applied to the counting tube and counting commences.

The slurry volume, 12 cm³, is great enough that a layer of solution thicker than the range of the Ca^{45} beta particles covers the precipitate. Thus one counts only the activity of the solution and not what has precipitated as $Ca_3(PO_4)_2$.

After 4 min of counting, counter potential is lowered on signal, the cylinder stops spinning, and the solution flows out through the central aperture. The total cycle takes 10 min.

Standardization of the instrument, programmed to occur twice daily, uses a third valve pipette and a standard solution containing 10 ppm of PO_4^{---}. The amount should be close to the value actually measured in the system; otherwise dissolution of the continually accumulating filter cake may prejudice the results. The same kind of prejudice affects actual measurements if there is a sudden large change of PO_4^{---} concentration, but true readings are obtained within two or three cycles of such a change.

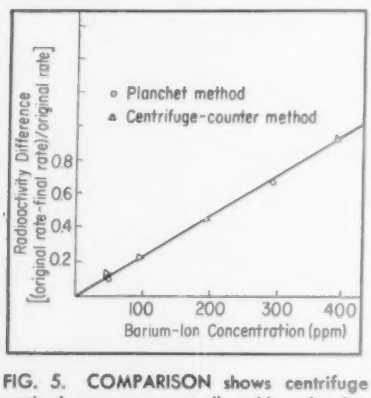

FIG. 5. COMPARISON shows centrifuge method compares well with planchet counting. Manually controlled centrifuge counter saves 10 min per assay

The system has outstanding advantages for process control. Data can be presented as counting rate, charging rate or current depending on the instruments one chooses. Systems using any of these data presentations are reliable and require only low activities. Volumes of the order of milliliters are used in such measurements, and separation is performed easily by centrifugation. Decay corrections are periodically eliminated by comparing the counting rate of the reagent with that of a known concentration of PO_4^{---}.

Special Counters

If the method is to be suitable for automatic process control, the counting sample must be presented to the counter as a fluid since automatic preparation of solid counting samples would probably be too slow to be workable. In a process-control laboratory, manual sample preparation might be fast enough, but surely liquid samples would be more convenient. We have used several types of counting arrangements for liquid samples. The best ones are those that combine the separation and sample presentation.

Two counters that do so are those of Figs. 3 and 4. The jacketed-counter-and-filter-stick combination is suitable for precipitates. When the fritted disk is removed, it becomes suitable for periodic sampling of two liquid phases. The centrifuge counter, too, is suitable for both liquid-solid and liquid-liquid systems.

In view of the usefulness of centrifuge counting, we have designed other types of centrifuge counters. One of them is a manual instrument with a volume of ~190 cm³. To use it one turns on the centrifuge, pours the sample in, records a count and then turns off the centrifuge to let the sample run out at the bottom. Only in preparing and adding the sample is precision technique required. The manual centrifuge saves ~10 min per assay over the planchet method and is more precise. On the other hand it requires about 100 times as much activity (~1 μc). Figure 5 shows a comparison of a series of analyses made with the centrifuge counter and another set of analyses of the same specimens made with evaporated samples on planchets.

In designing centrifuge counters one must consider the energy of the radiation, cost of the nuclide and frequency of use. To keep operating cost low with Ca^{45} in a continual analysis, for example, one must increase counting area to a maximum and reduce air absorption to a minimum. Moreover if the system is not to be washed between cycles, contamination on parts of the spinning cylinder not covered by liquid must be far enough from the counter window not to count. The optimal system has been found to be a 10-in.-long, 1.5-in.-diameter cylinder. For harder beta particles a shorter, wider cylinder is indicated; since air absorption is not important, one can allow more clearance between counter and sample.

Such systems work well even when the nuclide is not a pure beta emitter or when it is not practical or not possible to use enough solution to cover the heavier phase to infinite thickness. For example, Ag^{110} has some very energetic beta particles in its spectrum as well as some gamma radiation. Nevertheless assays in which this nuclide is the indicator produce a linear relation between radiation difference and the quantity to be determined. A simple correction permits one to correct the theoretical curve for infinite thickness to make a calibration curve for the actual determination.

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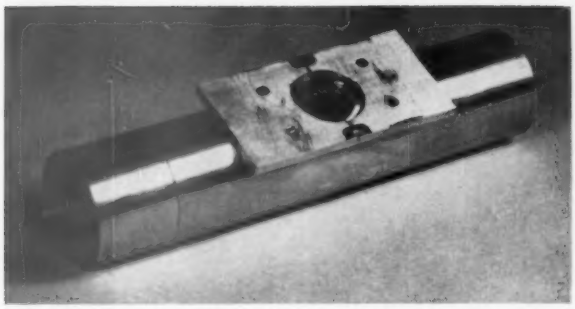

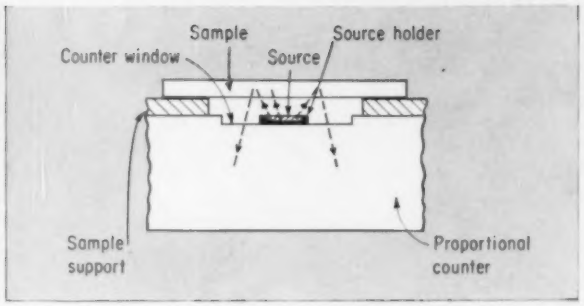

FIG. 1. Radioisotope-source and proportional-counter arrangement to detect fluorescent x-rays is pictured at left. Sketch at right shows how characteristic x-rays excited in sample by radiation from source enter counter volume

X-Ray Spectrometry with Radioactive Sources

A radioisotope source of gamma or bremmstrahlung photons can replace the customary x-ray tube in exciting characteristic x-rays to measure the thickness of materials or their chemical composition

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In conventional x-ray fluorescence spectrometry, electromagnetic radiation from an x-ray tube falls on a sample and the resulting fluorescent x-rays (which have energies characteristic of the elements in the sample) are analyzed with a crystal spectrometer and detected with a Geiger, scintillation or proportional counter. For many of the simpler applications of x-ray fluorescence a radioactive source of x- or γ-radiation can replace the x-ray tube (*1–4*). The radioisotope source is considerably cheaper than an x-ray tube and its output has an invariant energy distribution and a stable intensity (except for the slow, predictable decay).

The intensity of radiation from a radioisotope source is, however, considerably lower than that from an x-ray tube. To achieve adequate counting rate one must use short source-sample-detector distances and a proportional counter for energy resolution in place of the usual crystal spectrometer and its long path-length geometry. The resolution of the proportional counter is not as good as that of a crystal analyzer and this is the main restriction on the method.

An extra advantage of this method is that with the low photon intensities of isotope sources the radiation hazard is negligible.

The most successful application of the radioisotope x-ray fluorescence spectrometer has been to measure coating thickness. This is largely because the majority of coatings are simply one material on another and one can arrange to isolate the desired x-ray energies through a suitable choice of source or filter. Accuracies of 1 to 5% typically result from counting times of a few seconds.

The spectrometer also can perform chemical analysis; however, it is not as widely applicable in this area because most analysis problems concern complex systems and require accurate determination of a number of elements that may occur in quite small concentrations.

Apparatus

A typical arrangement of source and detector is shown in Fig. 1. The source, in the form of a 1-cm diameter disc, is located in the center of the proportional counter window. A suitable backing on the source prevents direct

radiation reaching the detector. When a sample is placed on the flat aluminum plate, fluorescent radiation emitted by the sample enters the annular part of the window not covered by the source disc. In this highly efficient "backscattering" geometry the source-sample-window path length is only about 1 cm and hence the relatively low photon output from the source (i.e. about 10^6 per second) is sufficient for many applications. Because of the large solid angles subtended at the source and window by the sample, variations in the sample to window distances for any particular set of measurements should not be greater than ± 0.025 cm.

Detection and filtration techniques. The x-radiation to be detected usually is in the range 2–70 kev with fluxes of the order 10^2 to 10^4 photons/sec. A Geiger-Muller counter can be used if the x-ray flux is less than 10^3 photons/sec and where it is permissible to count all the radiation incident on the counter irrespective of energy. Generally, however, one prefers an energy sensitive detector with a short resolving time that will discriminate against unwanted radiation and count high photon fluxes.

A good proportional counter (with pulse-height analyzer) can resolve the K x-ray peaks of elements only two or three atomic numbers apart. However, one experiences considerable practical difficulty in keeping the bias level and the over-all gain of the system constant enough to achieve this sensitivity.

X-ray filters that prevent unwanted radiation reaching the detector can remove the need for high-resolution detectors and highly stable pulse amplifiers. A filter takes the form of a foil that covers the detector window; the thickness and atomic number are such that the radiation to be counted is efficiently transmitted and that to be eliminated is strongly absorbed. As an illustration of the efficacy of the filter technique Fig. 2 shows the variation of mass absorption coefficient of nickel (Z = 27) with energy in the region of the Sn-L, Cu-K and Zn-K x-ray energies (3.4, 8.0 and 8.7 kev respectively). The K-absorption edge of the Ni filter effectively discriminates between the Cu-(Z = 29) and Zn-(Z = 30) K x-rays. If Cu- and Zn-K x-rays are passed through a Ni filter 0.0013 cm. thick, 60% of the Cu radiation is transmitted but only 1.5% of the Zn radiation.

Note that Ni, Cu and Zn form a trio of adjacent elements, Ni filtering out Zn but transmitting Cu. All trios of neighboring elements from Ti to Br exhibit this property; this range conveniently includes all the elements of the first transition series. Filtering in this manner is possible for elements differing by more than one atomic number but becomes less effective as this difference increases.

A less selective type of filter uses the steep slope of the absorption curve in the region of the K x-ray energy of the filter. For instance, this technique would remove Sn-L radiation when it might interfere with the detection of Cu-K radiation (Fig. 2).

Suitable sources. Although both charged particles and electromagnetic radiation can be used to excite characteristic x-rays, the latter are preferable.*

The ideal source of electromagnetic radiation should have long half-life, low maximum energy, low price and high specific activity. A maximum energy less than about 100 kev simplifies the problem of reducing the intensity of the radiation traveling directly from the source to the counter; also in this region interaction is primarily by photoelectric absorption so that scattered radiation is not usually important. A source emitting radiation with a broad energy distribution can excite a range of elements and thus has a wide application.

High specific activity makes possible a small compact source that can be mounted in the center of the counter window. The most suitable sources selected using the above criteria are Am^{241} and tritium and Pm^{147} bremsstrahlung (*5*). Tritium bremsstrahlung sources are available in the form of tungsten discs 1 cm diam × 0.5 mm. thick supporting a layer of titanium or zirconium about 7 mg/cm² thick. The tritium (half-life 12.3 yrs., maximum beta energy 18 kev) is absorbed into this layer at a high temperature to an activity of about 2.5 curies for H^3/Zr sources and 4.5 curies for H^3/Ti sources (*6*).

The Pm^{147} bremsstrahlung sources are available as Pm^{147} (half-life 2.6 yrs., maximum beta energy 223 kev) in an aluminum matrix compressed into a 1.0 cm diam × 0.2-mm-thick disc and covered at the front with a 0.005-cm-thick Al foil and at the back with 2 mm of gold. An activity of up to 100 mc of Pm^{147} is used.

Am^{241} (half-life 470 yrs., alpha and by electrodeposition of about 80 μC of

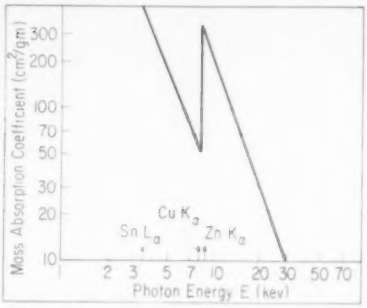


FIG. 2. Nickel K-absorption edge lies between K lines of Cu and Zn

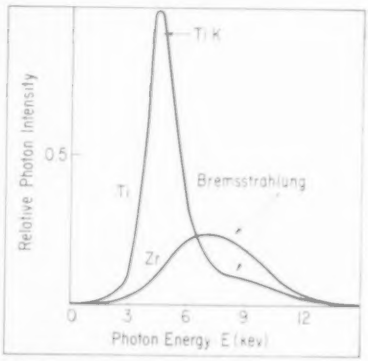


FIG. 3. Relative photon intensity vs. energy for H^3/Ti and H^3/Zr sources

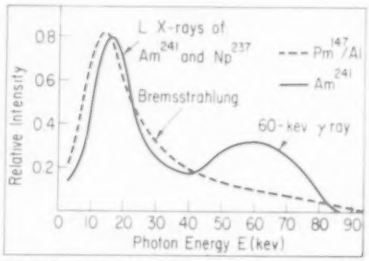
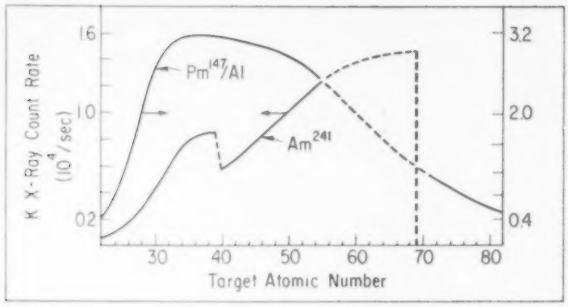


FIG. 4. Photon intensity vs. energy for Pm^{147}/Al and Am^{241} sources

* The excitation efficiency by alpha particles falls rapidly for x-ray energies above a few kev because the laws of conservation of energy and momentum limit the maximum transfer of energy. The very thin protective source covers that are necessary, combined with the high toxicity of alpha-particle emitters render them unsuitable for industrial use. Beta particles of suitable energy will excite characteristic radiation from every element in the periodic table. However, a high proportion backscatter toward the detector and must be deflected by a magnet (*2*). This results in a geometry of relatively low efficiency and makes for high beta activities.



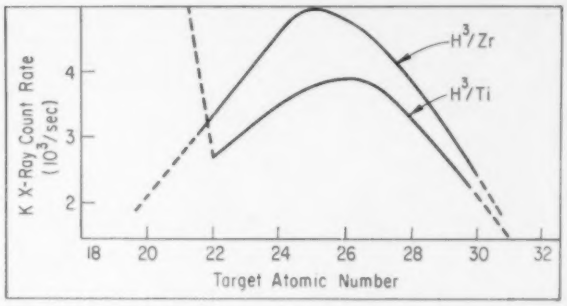


FIG. 5. Saturation excitation of K x-rays in pure elements as a function of atomic number for (a) Pm^{147}/Al and Am^{241} sources and (b) H^3/Zr and H^3/Ti sources. Samples were thick enough to produce maximum or "saturated" value of excitation

Am^{241} oxide onto a 1-mm-thick Au disc, 0.7 cm in diameter. A 0.1-mm-thick Al-foil covering welded to the Au backing provides protection and stops the unwanted alpha particles.

Figures 3 and 4 give the experimental spectral distribution of the electromagnetic radiation from these sources. Those for Pm^{147} and Am^{241} were obtained with a scintillation counter that had a 4.1-cm diameter, 0.10-cm-thick NaI(Tl) crystal, a 0.013-cm-thick Be window and an E.M.I. type 6097S photomultiplier. Spectra for H^3/Zr and H^3/Ti were measured with the proportional counter* shown in Fig. 1. The counter had a beryllium side window 2.2 cm in diameter and 0.05 cm thick and was filled to 77-cm Hg with a 70:7 Xe/CH_4 mixture.

Source performance. Figure 5 shows the intensity of characteristic K x-radiation excited in pure elements with the above sources for samples thick enough to produce saturation excitation. The detectors used were the same ones described above. The curves are corrected for absorption efficiency and window transmission of the detector but for the scintillation counter these corrections are very small.

APPLICATIONS

The two main fields of applications for radioisotope fluorescence spectrometry are: (1) chemical analysis of simple systems such as solutions, ores and binary alloys and (2) measurement of the thickness of thin layers of a substance on a relatively thick backing.

Chemical Analysis

Theoretically one could selectively count the characteristic radiation from each of the individual components of a system by means of pulse height analysis. In practice complications arise because of the finite resolution of the detector, the low intensity of the excited radiation, and selective absorption and re-emission of the radiation by the different components. However, rough chemical analysis is possible in many cases. The two examples of alloy analysis given in Appendix 1 serve to illustrate two important points to be considered in making such analyses:

- Choice of a source to excite only the desired x-rays with maximum efficiency
- Use of a filter to remove an unwanted x-ray of energy very close to that of the required radiation

Table 1 lists the method used and the accuracy obtained in some other chemical analyses. Mellish and Payne (7) have successfully determined traces (i.e. 0.1% to 5%) of a particular component of an alloy or mixture in a limited number of cases with monoenergetic electron-capture isotopes as exciting sources.

Coating Thickness

The thickness of a thin layer of one material on another of different composition can be measured either by exciting the characteristic radiation of the top layer only (the intensity of which varies with thickness up to a saturation value) or by exciting that of the base substance ("backing") and measuring its attenuation by the surface layer. Appendix 2 discusses the simplified theory for each of these techniques. We will present here one example of the use of each technique:

TABLE 1—Chemical Analysis of Alloys and Mixtures

Compound	*Principal components*	*X-ray used*	*Source used*	*Remarks*
Solder	Sn, Pb	Sn K (25 kev)	Am^{241}	Pb L X-rays biased out. For 1–5% Sn range, 8% accuracy in 1 min count
Nickel in aluminum (7)	Ni	Ni K (7.5 kev)	H^3/Zr	1% Ni measurable. For 1–4% Ni range, 2% accuracy in 1 min count
Silver bromide photographic emulsions	Ag, Br	Br K(12 kev) and/or Ag K(22 kev)	Am^{241}	About 2% accuracy in 1 min count at Ag density of 10 grains/ft²
High tungsten steel	W, Fe, Co, Cr	W K (59 kev)	Pm^{147}/Al	5%–20% W range, 2% accuracy in 20 sec count. Al filter used to cut out scattered radiation and low energy X-rays
Hydrocarbons for cobalt content	H, C, Co, Fe (traces)	Co K (6.9 kev)	Pm^{147}/Al	Balanced filters of Mn and Fe isolated Co K x-ray; counting time 200 sec; 0–20 gm/l Co; ult. sensitivity of 10 ppm Co

* Type PX130, 20th Century Electronics Ltd.

Excitation of coating. In a test to determine the thickness of titanium-based paint, blocks of polyester resin about 5 cm square by 3 mm thick were coated with various known thicknesses of paint containing 16.3% titanium, 41.4% oxygen, 39.8% carbon and 2.5% hydrogen by weight. Each sample was counted in turn by the proportional counter arrangement of Fig. 1. A plot of the count rate of Ti K x-rays (4.5 kev) against thickness fits the curve

$$I = 1{,}500(1 - e^{-380t}) \text{ counts/sec} \quad (1)$$

where t is the paint thickness in cm.

Measurement of paint thickness greater than about 12×10^{-3} cm is impossible because of saturation.

By differentiating Eq. 1 we obtain

$$\frac{\delta I}{I} = \frac{\delta t}{t} \frac{380e^{-380t}}{1 - e^{-380t}} \times t = 0.34 \frac{\delta t}{t}$$
$$\text{for } t = 5 \times 10^{-3} \text{ cm} \quad (2)$$

Also from Eq. 1 $I = 1{,}280$ counts/sec at $t = 5 \times 10^{-3}$ cm. Thus a counting time of about 4½ minutes would determine a paint thickness of this order to within an accuracy of 1%. As many paints and enamels contain Ti this method is capable of wide application.

Excitation of backing. To illustrate the absorption technique we measured with the proportional counter the count rate from samples of tinplate. The samples were steel sheets of various thicknesses (all greater than 0.005 cm) covered with electroplated layers of tin of thickness 0 to 1.5 microns. An equation of the same form as Eq. 4a (see Appendix 2) fitted the curves of count rate against tin thickness

$$I = 5.2 \times 10^3 e^{-0.53t} \quad (3)$$

where I is counts per second and t is in microns.

From this equation we can see that for a thickness of 0.75 microns a 1% variation in thickness corresponds to a 0.4% change in count rate which can be measured in 70 seconds.

Both the above methods are being considered for routine process control. Table 2 lists some other successful applications.

TABLE 2—Coating Thickness Measurements

Substance	*Coating*	*Backing*	*X-ray used*	*Source*	*Filter*	*Remarks*
Electroplated galvanized steel	Zn	Fe	Fe K (6.4 kev)	H^3/Zr	Ni	Coating thickness range 0–120 10^{-4} in. Accuracy 1% in 10 sec count.
Hot-dipped galvanized steel	Zn	Fe	Fe K (6.4 kev)	H^3/Zr	Ni + Fe	Coating thickness range 0.7–1.8 mils. Accuracy ~2% in 100 sec count.
Electroplated copper on steel	Cu	Fe	Fe K (6.4 kev)	H^3/Zr	Fe	Coating thickness 10^{-4} in. 2% accuracy in 3 min count.
Platinum on titanium	Pt	Ti	Ti K (4.5 kev)	H^3/Zr		Coating thickness 0–50 10^{-4} in. 2% accuracy in 10 sec count.
Silver-plated copper wire	Ag	Cu	Cu K (8.0 kev)	H^3/Zr		H^3/Zr source excites Cu K but not Ag K. Any source which excites Ag K also excites Cu K.
Nickel-plated copper	Ni	Cu	Ni K (7.5 kev)	H^3/Zr	Co	
Iron-based ink on coated and uncoated paper	Prussian blue ink (Fe)	Paper with Ba and Ti fillings and glaze coatings	Fe K (6.4 kev)	H^3/Zr	Al	Range of ink thickness 0–4 microns. Also measurable: glaze coatings and ink on Al printing plates.

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APPENDIX 1

Examples of Chemical Analysis

Cu-Sn alloy. An easy example of fluorescence analysis is that of a binary alloy of elements with widely different atomic numbers. The spectrum obtained with a single channel pulse height analyzer on exciting a 1:1 Cu-Sn alloy with the H^3/Zr source is compared with the spectra for pure Cu and Sn in Fig. 6a. The Cu K radiation (8.0 kev) is excited to a much higher degree than the Sn L radiation (3.4 kev). A series of alloys were analyzed and graphs of count rate against percentage composition are shown in Fig. 7. Since the counts recorded in the region of the Sn L peak are mainly background and therefore do not change much with percentage of tin, one need not bias out the Sn L radiation, and can analyze the percentage of copper very simply. From the slope of the curve of total count rate against percentage copper we find that a 50% copper content, for example, can be determined to 50.00 ± 0.33% in a counting time of 100 seconds.

If the H^3/Ti source is used, its high proportion of Ti K x-rays excites appreciable Sn L radiation; the intensity of the latter is about the same as that of the Cu K x-rays. Thus both the count rate for the Sn L peak and that for the Cu K peak are sensitive to changing composition. By biasing out either the tin L or the Cu K x-rays the percentage Cu or Sn may be obtained directly. As Fig. 2 shows, a Ni filter will also discriminate against Sn L radiation.

Cu-Zn alloy. The most difficult binary alloy to analyze by this technique is one where the elements are adjacent in the periodic table. Here the characteristic radiation cannot be resolved with a proportional counter and since both radiations are excited about equally one must resort either to biasing or to filtering out most of the contribution from one element. Both methods were employed to analyze a series of Cu-Zn alloys.

By setting the bias so that most of the pulses due to the Cu K x-rays are biased out, the count rate recorded for a Cu-Zn alloy determines the % zinc. Biasing in this manner requires elaborate electronic equipment to keep gain bias levels stable enough to obtain reproducible results.

On the other hand, a Ni x-ray filter to absorb the Zn x-rays can be used to obtain similar accuracy without any modification of the equipment (see Fig. 2). The filter method determines the % copper.

Fig. 7 also shows a calibration curve of counting rate against % copper for various brasses and a 0.0013 cm thick nickel filter. From the slope of this graph a 90/10 Cu-Zn alloy, for example, is analyzed as 90.0 ± 0.9 % copper in a counting time of 200 sec.

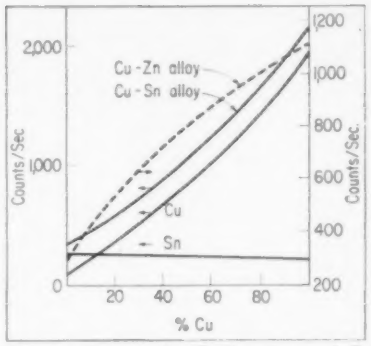

FIG. 6. Spectra for Cu-Sn alloy and Cu and Sn for excitation by H^3/Zr source

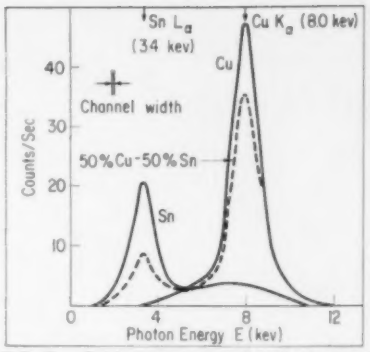

FIG. 7. Calibration curves for Cu-Sn and Cu-Zn alloys with H^3/Zr source

APPENDIX 2

Theory of Thickness Determination

Excitation of covering layer. If there is no fluorescent radiation is excited in the backing, the equation for the variation of intensity of excited x-radiation in a layer of thickness χ cm is (*8*)

$$I = \frac{k_1 k_2 I_0 N_\sigma \omega_k}{(\bar{\mu}_1 + \mu_2)A} \{1 - \exp[-(\bar{\mu}_1 + \mu_2)\rho\chi \operatorname{cosec} \theta_{avg}]\} \quad (1A)$$

or simply

$$I = I_{max}(1 - e^{-bx}) \quad (2A)$$

where: k_1 is a constant depending only on geometry;

k_2 is a measure of the absorption of fluorescent radiation in the proportional counter window, the proportional counter gas filling and the air gap between source, target and detector window (for a given source, detector and geometry, k_2 varies only with energy of fluorescent radiation);

I_0 is the intensity of radiation from the surface of the source and, since the source spectrum is continuous, should strictly be written as

$$I_0 = \int_{E_k}^{E_{max}} I(E)dE$$

where E_k is the energy of the absorption edge;

N is Avogadro's number;

σ is the photoelectric cross-section for ionization of the K shell of the target element by the incident spectrum I_0;

ω_k is the fluorescence yield for the target element of atomic weight A;

$\bar{\mu}_1$ is the mean mass absorption coefficient for the exciting spectrum in the sample of density ρ and μ_2 the mass absorption coefficient for the fluorescent x-ray;

θ_{avg} is a measure of the mean glancing angles of incidence and re-emission for the exciting and excited radiation.

θ_{avg} is a function of geometry and with the broad-beam geometry used in this investigation would be very difficult to calculate. A value of 60° for θ_{avg} was found to be consistent with theory and experiments performed with the apparatus shown in Fig. 1 (*8*). For feasibility predictions, which are little more than an order of magnitude calculation, θ_{avg} can be taken as 90°.

From Eq. 1 we see that for thicknesses such that $b\chi = (\bar{\mu}_1 + \mu_2)\rho\chi \operatorname{cosec} \theta_{avg} \geq 3$, the excitation has reached a saturation value (I_{max}); this value of thickness is determined for a given material by the sum of $\bar{\mu}_1$ and μ_2. For a given material μ_2 is fixed and μ_1 can vary from its maximum value of about 7 μ_2 at the top of the absorption edge to a very low value at high energies. Thus one can extend the range by using an exciting source of higher energy, but since the excitation cross-section is proportional to $\bar{\mu}_1$, the characteristic x-ray intensity will then decrease accordingly.

Excitation of backing. The equation for variation of count rate with thickness of coating when the fluorescent radiation in the backing is excited to saturation is:

$$I = \frac{k_1 k_2 I_0 N_\sigma \omega_k}{(\bar{\mu}_1 + \mu_2)A} \exp[-(\bar{\mu}_3 + \mu_4)\rho\chi \operatorname{cosec} \theta_{avg}] \quad (3A)$$

or simply

$$I = I_{max}\, e^{-dx} \quad (4A)$$

The notation is the same as in Eq. 1A except that $\bar{\mu}_1$ and $\bar{\mu}_3$ are the mean mass absorption coefficients for the exciting radiation in the backing and the surface layer respectively, and μ_2 and μ_4 the corresponding values for the fluorescent radiation of the backing. Any excited radiation in the surface layer is assumed negligible. We also assumed that the backing is thicker than "saturation" thickness. This is true for steel with thicknesses greater than 0.005 cm. The approximate validity of the factor

$$\frac{k_1 k_2 I_0 N_\sigma \omega_k}{(\bar{\mu}_1 + \mu_2)A} = I_{max} \quad (5A)$$

has been verified (*8*).

Range of thickness measurable. When the coating is excited we saw above that the range of thickness which can be measured is limited to $\chi \leq 3b$. For high energy radiation incident normally on the surface the maximum measurable thickness is given by

$$\mu_2 \rho\chi = 3 \quad (6A)$$

If the backing is excited and the radiation obeyed an equation of the form of Eq. 4A, there would be no upper limit to the measurable thickness range. In practice, because of the absorption of the incident radiation, excitation of some radiation in the coating and radiation scattered from the coating, there is a limit which in many cases is given approximately by Eq. 6A.

Figure 8 shows the product of ρ and χ given by Eq. 6A for different atomic number materials. One can take this curve as the absolute upper limit to the thickness measurable by either technique. This thickness is also the minimum for the backing material to give saturation excitation to its K x-ray.

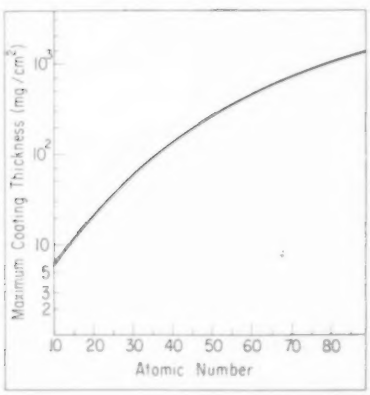

FIG. 8. Maximum coating thickness measurable by exciting K x-rays

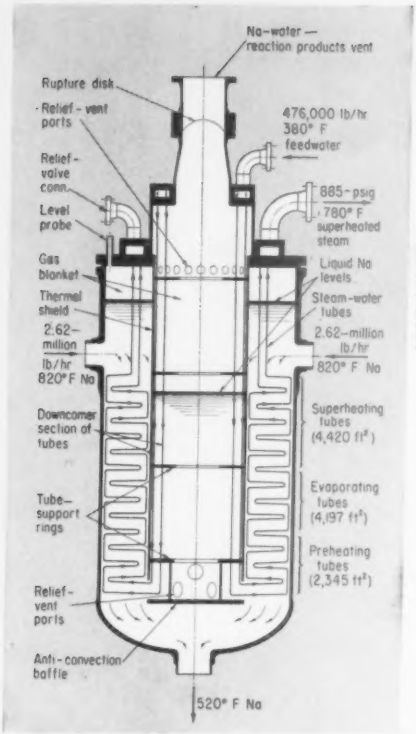

FIG. 1. FERMI STEAM GENERATOR, each (there are 3) of which transfers 489-million Btu/hr, has preheater, evaporating and superheating sections all within one shell. Sodium is within shell; water passes through 1,200 tubes. Design approach with single-wall tubes accepts chance of leak, provides for safe disposal of sodium-water reaction products via rupture disk and vents

FERMI

HALLAM

Two Approaches for Sodium-System Equipment:

Fermi and Hallam Steam Generators

By FRANK BONI and PHILIP S. OTTEN
Griscom-Russell Co., Massillon, Ohio

Excessive thermal stresses in sodium-heated steam generators tend to fracture tubes, tubesheets, shells and junctions—thus permitting vigorous sodium-water reactions. Two new steam generators take different paths to reduce these stresses and the effects of a tube rupture

CONTRASTING DESIGN approaches are being taken for the steam generators for the Fermi and Hallam plants. Both aim to resolve the problems of excessive thermal stresses and interleakage.

Operating experience with sodium-cooled nuclear power plants has shown clearly the key role that steam generators play in the reliability of sodium-reactor systems (*1*, *2*). Based on this experience, two different design approaches are being used to resolve these problems in the steam generators we have built for the Enrico Fermi Atomic Power Plant and for the Hallam Nuclear Power Facility (*3*). Both cost and performance were key factors in the selection of materials.

In the three once-through Fermi generators (Fig. 1) hot sodium is in the shell, and water and steam flow through the single-wall tubes, which are arranged in a unique involuted tube bank. Each of the three Hallam steam generators (Fig. 2) has a thermal-circulation kettle-type evaporator and separate superheater with water or steam in the shells; sodium flows through the bayonet tubes (Fig. 3) in a twice-through path in both the evaporator and superheater sections. To monitor tube leaks in the Hallam generators, each bayonet has a duplex-tube arrangement with helium in an annular space between the tube that contains the sodium and the one that excludes the water or steam.

Fermi Generators

As shown in Fig. 1, to transfer 489-million Btu/hr, 2.62-million lb/hr of sodium at 820° F enters each of the two 12-in. nozzles on the shell side, flows down over the banks of the tubing in the annulus between the shell and the thermal shield and then leaves at 520° F through the nozzle at the bottom (Δp between the sodium level and the outlet

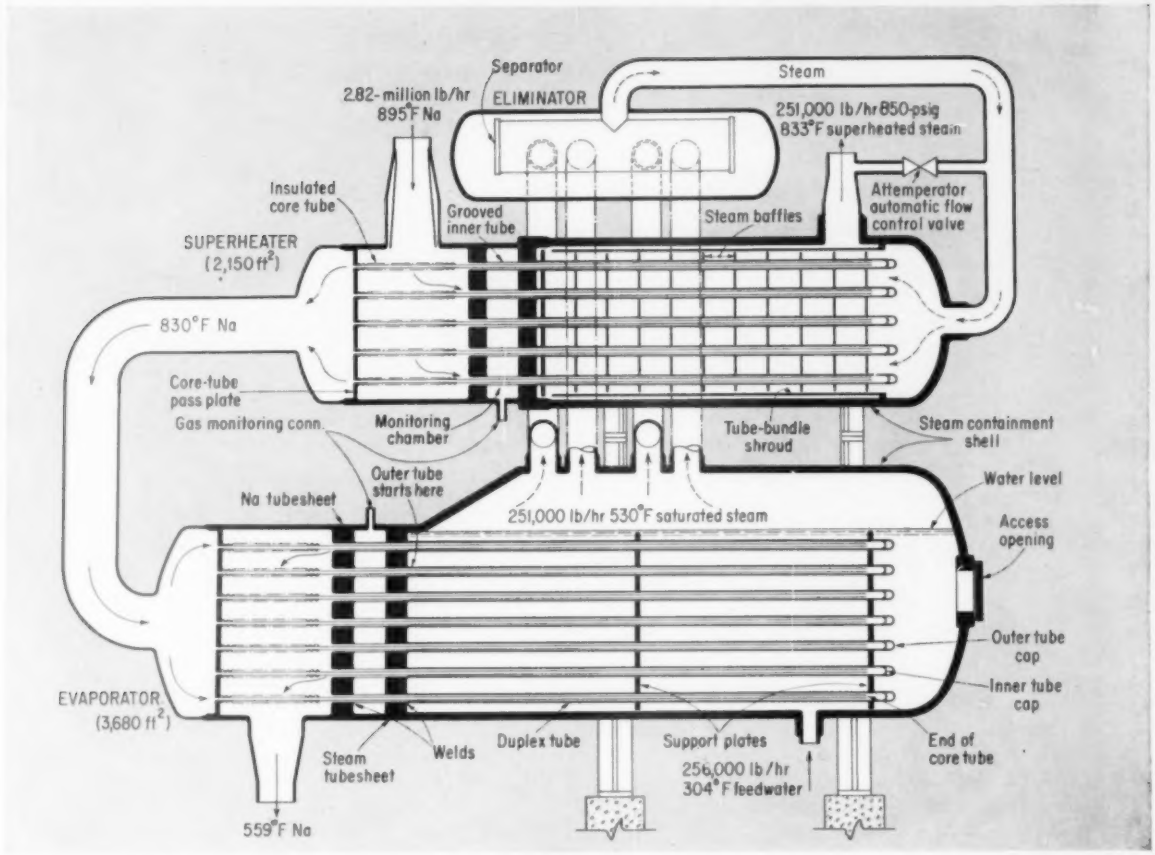

FIG. 2. HALLAM STEAM GENERATOR, each (there are 3) of which transfers 288-million Btu/hr, consists of separate evaporator, eliminator and superheater sections. Sodium passes through duplex bayonet tubes in evaporator and superheater, which have water or steam within shells. Steam from surface of water in evaporator travels up risers to eliminator, where remaining entrained moisture is removed centrifugally (4). Any leakage will be detected by change in pressure of helium between duplex tubes

is ~4 ft Na). Feedwater (476,000 lb/hr) at 380° F enters the top central annular tube sheet, flows down inside the thermal-shield tubes, up through the 1,200 tubes (each ⅝ in. o.d., 42-mil wall, 78 ft long, exposing a total of 10,962 ft² surface to the sodium) in the annular region, where it is evaporated and superheated; then it rises to the outer annular header and leaves at 780° F, 885 psig. Velocity of the dry saturated steam is only 23 mph, so it will not erode the tubing. The mean-temperature drops and heat-transfer rates in the preheater, evaporator and superheater are, respectively, 73.5° and 495, 72.3–203° and 825–497, and 108° F and 187.3 Btu/hr/ft²/° F.

Reduce thermal stresses. An inert-gas blanket in the upper space in the steam generator reduces the steady-state temperature differences across the tube sheets (Figs. 1 and 4). It also protects the upper tubesheet from sudden thermal transients in the sodium (the space also acts as a surge or expansion tank). The thermal shield (between the central core—including the downcomer tubes—and the annulus where sodium flows across the tubes) confines the sodium flow over the tube bank. The ports in the thermal shield above the liquid level connect the two gas spaces so as to balance pressures when the sodium level varies as flow and temperature change during operation.

If a tube leaks . . . The design approach is to accept the possibility of a rupture, to contain it if it occurs, and to dispose of the reaction products safely. If a tube leaks, steam and water-sodium reaction products can escape through the central well or up through the annulus and the ports in the thermal shield, then out through the rupture disk. Tests indicate sodium-water reactions would lead to ~70 psi pressure in the shell. If a tube ruptures during full-load operation, the temperature would peak at nearly 1,700° F, but tests indicate no damage to surrounding tubes. Tube-to-sheet attachments will be accessible through the annular openings at the upper end of the steam and water manifolds. This will permit the operators to plug a tube if it leaks. If tube replacement ever becomes necessary, it will be done in clips of eight tubes at a time.

Advantages. A Fermi-type once-through steam generator with sodium in the shell and water in the tubes (a) has lower capital cost because there are fewer tube-to-tubesheet attachments, tubesheets, steam heads and no steam drum; (b) can be drained of sodium completely (and surfaces exposed to sodium can be cleaned readily); (c) has thinner-wall tubes because the high pressure is inside the tubes; (d) has

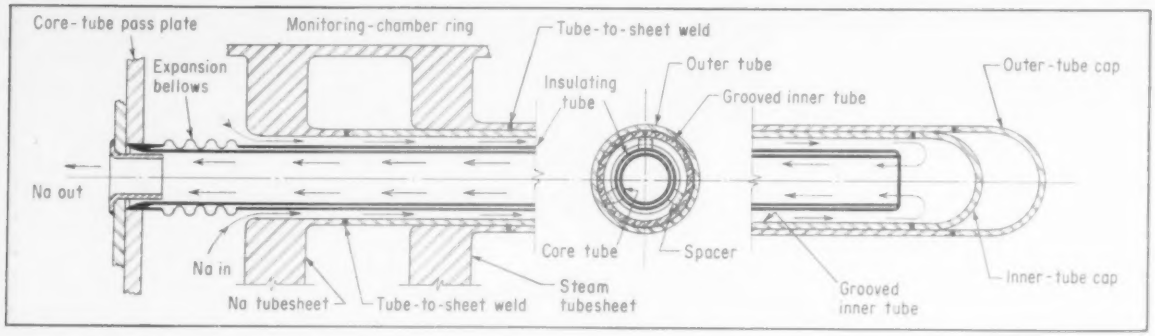

FIG. 3. DUPLEX BAYONET TUBES in Hallam steam generator permit using change of pressure of helium in annulus to indicate failure of either wall separating sodium and water in shell. In operation, sodium in superheater flows down annulus (between the insulating core tube and inside grooved tube) to cap end, then returns inside core tube (reverse of flow in evaporator)

thinner shell walls with low-pressure sodium in the shell.

The price of the three Fermi steam generators was ~$41/ft² of effective tube surface. Future units of this type probably would cost $30–35/ft².

Disadvantages. With high pressure in the tubes there is a greater chance of any failure enlarging to produce a gross opening in the tube. This could allow a large amount of water to react with the sodium (if the high pressure were in the shell, failure by buckling of the tube wall would not lead to such serious leakage since tubes often collapse completely without leaking). The possibility of a large tube rupture requires standby disposal equipment for reaction products.

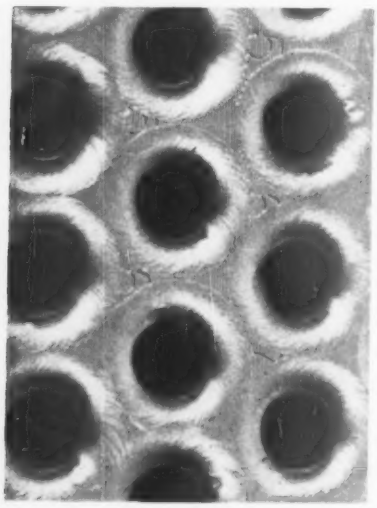

FIG. 4. TUBE-TO-SHEET WELDS in Fermi steam generators were made using automatic heliarc (tungsten electrode) welding gun after tubes were roller-expanded into recession in top of tubesheet. This type of semi-internally welded joint should be reliable since it is somewhat restrained radially and tightens as steam pressure inside tube rises. Also, separation forces will be very low because entire tube-clip structure is flexible and gas insulates tubesheet from sodium temperature changes

Since any scale-forming solids in the water will deposit in the once-through tubes and decrease performance, very pure water is required. Of course there need be no hesitation in using this configuration if a properly designed evaporator is used to keep the water essentially solid-free. Evaporator tests indicate impurities can be held to ~0.006 ppm during unattended steady-state operation, with short-term peaks of ≤0.020 ppm during load changes (*4, 5*). The worst that can be expected for short periods is 0.100–0.250 ppm under abnormal transient operation. Upon initial startup a maximum 0.003-ppm silica carryover is obtained without any attention to the evaporator, during this time measurements show a total of 0.150–0.200 ppm total solids (*5*). As a result of these tests, modifications to evaporator design are expected to yield still better purity.

Hallam Generators

The Hallam steam generators use a more conventional approach than that of the Fermi Plant. The evaporator section is a kettle type with water in the shell and molten sodium as the heat source inside the tubes—similar to a fire-tube boiler. As shown in Figs. 2 and 3, to transfer 288-million Btu/hr, 2.82-million lb/hr sodium at 895° F enters the superheater sodium inlet plenum, flows through the annulus (between the insulating tube and the inner monitoring tube) to the cap end of the bayonet tube, back through the core tube to the superheater outlet plenum; then at 830° F it flows down to the evaporator, into the core tube, out the annulus and leaves the nozzle at 559° F. Feedwater (256,000 lb/hr) at 304° F goes up into the evaporator shell, is heated to 530° F in passing over the 3,680 ft² of hot tubes, forms 251,000 lb/hr of saturated steam, which rises into the superheater shell where it passes over the 2,150 ft² of hot tube surface and is superheated to 833° F.

Reduce thermal stresses. The insulated core tubes permit use of bayonet tubes for the wide temperature ranges that prevail in both evaporator and superheater sodium (*6*). The bayonet-tube design (Figs. 2 and 3) eliminates differential expansion and thermal stresses between the shell and tube, between individual tubes and between legs of the same tube (such as in U tubes). The only remaining tube stresses are the moderate ones in the span between the double tubesheets and those caused by hydrostatic pressure and thermal gradients in the tube wall. In the evaporator, transient stresses in the tubesheet and the tube joints are alleviated by both the bayonet-tube design and the sodium flow pattern. Sharp temperature changes in the incoming sodium do not fall directly on the double-tube-sheet system but rather on the thin and flexibly supported core tubesheet. Of course, steady-state thermal stresses at any power also are less because the temperature difference across the tubesheets is only that between the outlet sodium and the saturated steam. Because of the kettle design and the closeness of the outlet-sodium and steam temperatures, changes in power level have little effect on the thermally induced stresses at the tube-to-sheet junction. In the superheater, the sodium countercurrent flow and the close approach of the superheated steam to the inlet sodium

temperature (combined with the low surface-heat-transfer coefficient of the superheated steam) tend to minimize thermally induced stresses in the steam tubesheet and tube-to-sheet welds.

If a tube leaks . . . The philosophy is to use a duplex tube with helium in the annulus to monitor for any leakage; if a leak occurs, the operator can shut the unit down for repairs before any sodium-water reaction can occur. Although the inner and outer tubes are mechanically expanded into intimate contact (and the heat-transfer bond improves as the sodium in the inner tube gets hotter) the helium can always circulate to and from the monitoring chamber through the 66 semicircular grooves (8 mil deep, 16 mil wide) on the outer surface of each inner tube (Fig. 3). The pressure of the helium is between that of the steam and that of the sodium. Thus, if helium pressure drops, there is a leak from the tube on the sodium side; conversely, if helium pressure rises, the steam-water side is leaking (*6*).

Advantages. The bayonet design permits butt-welding the tubes to the sheets (Fig. 3); these welds can be radiographed to assure their integrity. There are no crevices in which impurities can concentrate or crevice-corrosions can occur; stress relieving operations do not impair structural reliability; also, the generous fillet in the tube-to-sheet attachment gives a more gradual change in heat flux and this reduces thermal stresses and stress concentration. With the hot low-pressure sodium within the tubes and high-pressure water outside the tubes, the pressure would tend to close a leaking tube rather than aggravating the defect; also, the hot sodium in the tube tends to assure good contact heat transfer across the duplex tube walls. The kettle-type evaporator is inherently stable; that is, power surges from 10% to 100% of full power will cause the water level in the evaporator to rise only a few inches.

Since the shell bottom and tube surfaces can be blown continuously during operation to keep solids content small, water-treatment requirements for this steam generator are less stringent than for the Fermi units. An eight-month test of a Hallam-type design showed that a heat-transfer rate of 800–900 Btu/hr/ft²/° F can be sustained without cleaning or maintenance (*7*). This is equivalent to operating at the predicted clean heat rate, although examination revealed 5–8 mils of oxide on all tube surfaces (with a 0.0005 fouling factor, the calculated heat rate would be 570 Btu/hr/ft²/° F).

Disadvantages. Because of the four concentric tubes in the duplex bayonet-tube design, the three Hallam steam generators cost about 3½ times as much per unit effective area as the Fermi-type once-through generators. Furthermore, the potential of the bayonet design is limited since it probably is not practical to increase the pressure of the steam side beyond 1,500 psi. For design temperatures above 950° F it would be desirable to divide the superheater into two sections: a low-temperature portion (to heat the steam to ~150° F above the saturation temperature) built with ferritic materials, and a hotter austenitic section.

Cost reductions for either type of steam generator might be possible in the future if operating experience permits statistical quality control of tubes and welds (rather than the present 100% inspection).

Materials

In both the Fermi and Hallam steam generators, carbon steel is used for water- and steam-containing parts that contact sodium cooler than 650° F; 2¼Cr-1Mo stainless steel serves for hotter parts because it retains its strength better than do other ferritic materials.

Fermi. The Fermi steam generator is made of 2¼Cr-1Mo alloy steel, which is the strongest ferritic material for containing water, steam and sodium up to 850° F. In tests this alloy held sodium during unexpected excursions to temperatures greater than 1,200° F with no perceptible damage to the metal structure (*7*). But other tests indicate sodium hotter than 850° F leaches carbon from this alloy and so lowers the alloy strength by 20%. Since this leaching apparently is a general (rather than localized) attack, the Fermi design assumptions merely compensate for this 20% reduction in the ASME code allowable strength. To resist corrosion on the water side, a tightly adherent blue-oxide coating is permitted on the tubing.

Hallam. On the other hand, we use a 5Cr-½Mo ferritic alloy in contact with the sodium hotter than 850° F in the Hallam superheater (*8*). But we have stayed with 2¼Cr-1Mo in the Hallam evaporator, which will not be as hot.

Why no austenitic steels. Although austenitic stainless steels are stronger than ferritic ones in steam generators where the steam is superheated more than 150° F above saturation temperature, the austenitic steels are more expensive. They have served successfully where the water has been properly deaerated and purified for once-through boiler operation. But operating experience (*7, 9–11*) indicates that austenitic stainless steels do not contain boiling water or slightly superheated steam satisfactorily when more than very little oxygen and few chloride ions are in the water. Other materials, such as nickel-chromium alloys, that would be satisfactory at the temperatures in these steam generators were eliminated on the basis of cost.

Because of its higher thermal conductivity and lower expansion coefficient, ferritic steel has an added advantage over austenitic steel for use in equipment subjected to strong thermal shocks; since thermal stresses are ~40% less, the ferritic equipment lasts longer.

Future improvements. Since the designs of both these units adhere to the ASME code, only code-approved materials were used. However, a material containing more chromium and a stabilizer such as titanium or niobium might be satisfactory. Steels having a greater molybdenum content (e.g., 5Cr-1%Mo) might provide greater strength at elevated temperatures. The promise of these materials is being studied.

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Gamma-Ray Attenuation Coefficients

By **PETER F. BERRY,** *UKAEA, Wantage Research Laboratory, Wantage, Berkshire, England*

RADIOACTIVE SOURCES of low-energy electromagnetic radiation are finding extensive use in instruments for determining thickness, density and composition. To select the most suitable source for a specific measurement, predict the performance of an instrument, calculate detector efficiency or select a suitable filter, one must refer to values of absorption coefficients for narrow-beam geometries. The graph below gives in a simple form the mass absorption coefficient as a function of gamma-ray energy and atomic number of absorbing material. The graph is an extension to low photon energies of Chappell's graph in NUCLEONICS, Data Sheet No. 10 (*1*), and was plotted from the values given by Grodstein (*2*) and Allen (*3*).

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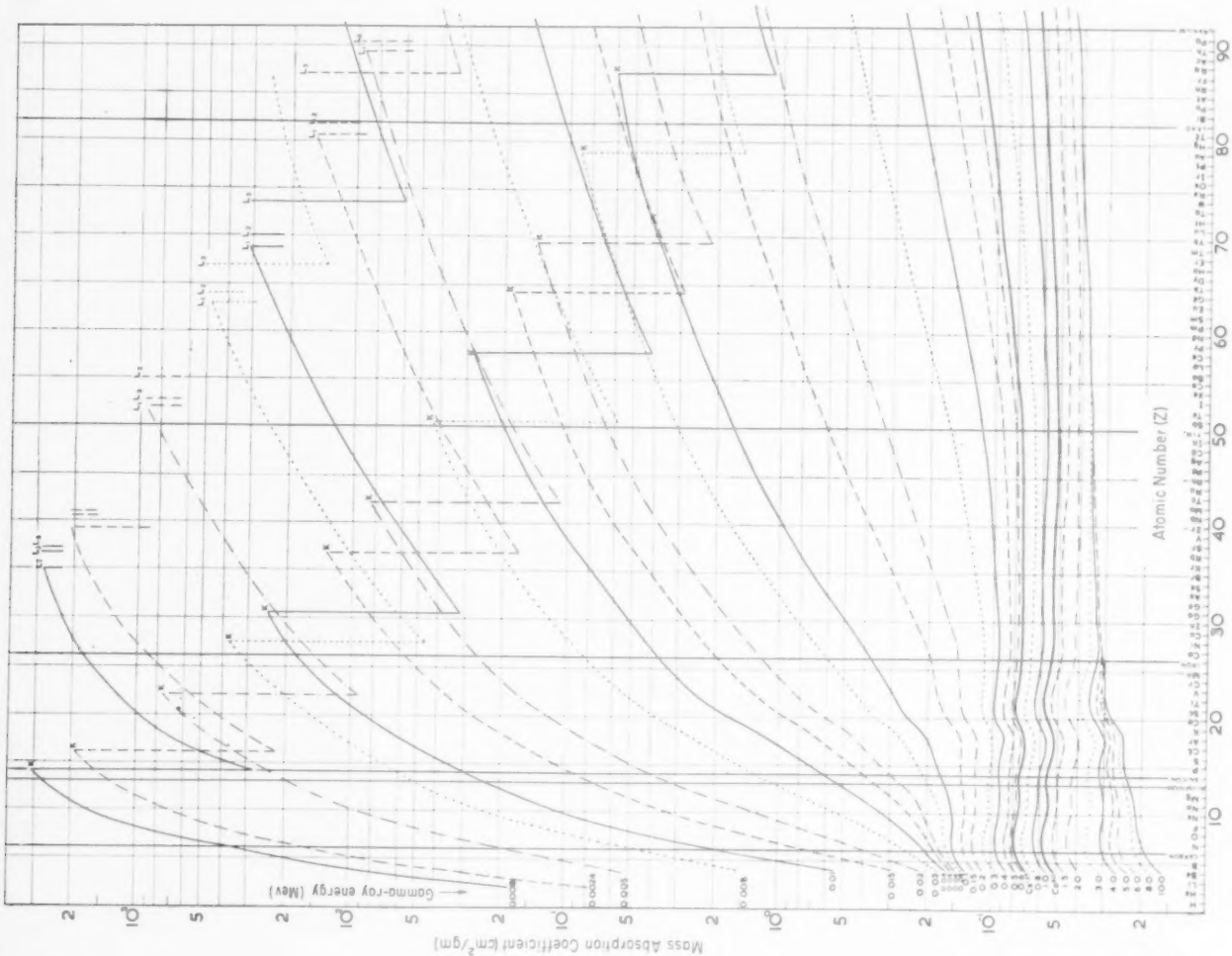

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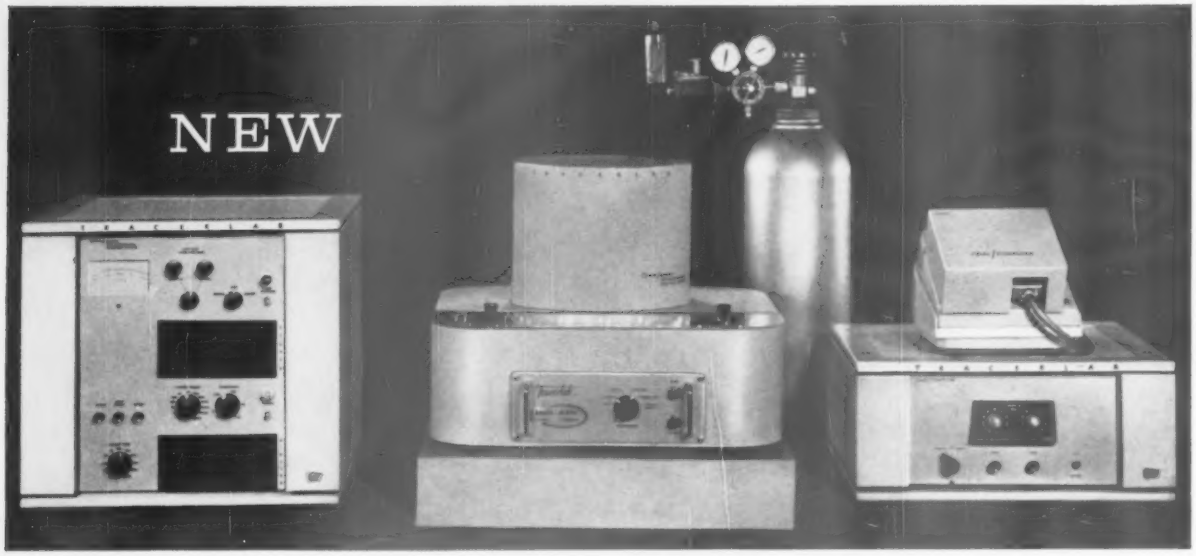

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OFFICIAL PROGRAM

1961 Meeting, Exhibition and Activities Schedule

HEALTH PHYSICS SOCIETY

Prepared as a service to the
HEALTH PHYSICS SOCIETY
by **NUCLEONICS** Magazine

1961 – HEALTH PHYSICS SOCIETY

Meeting, Exhibition and Activities Schedule

Sunday, June 11

12:00—9:00 pm	Registration	
12:00—9:00 pm	Tour Preparation	
1:00 pm—4:00 pm	Board of Directors Meeting	

Monday, June 12

7:30 am—5:00 pm	Registration	
8:30 am—5:00 pm	Certification Exams	
7:30 am—5:00 pm	NTS Tour	
6:00 pm—10:00 pm	Exhibition will be open and from 9:00 am to 5:30 pm thereafter	
6:15 pm—7:30 pm	Host Cocktail Party at Riviera Hotel (members, wives, students and exhibitors)	

Tuesday, June 13

		Hotel
9:00 am—5:30 pm	Exhibition; Health Physics Society Business Office and Health Physics Society Placement Office will be open	
9:00 am—9:15 am	Opening remarks: J. S. Laughlin, H. E. Grier	Riviera
9:15 am—12:00 noon	General Session: Education and Training in Health Physics (Dedicated to Dr. Elda Anderson)	"
1:45 pm—4:45 pm	Session A: Internal Emitters I, Inhalation Studies	"
	Maximum Permissible Exposures	"
1:50 pm—4:45 pm	Session B: Development and Design of Laboratory and Plant Equipment	Thunderbird
1:45 pm—4:45 pm	Session C: Miscellaneous Topics In Health Physics	"

Wednesday, June 14

9:00 am—5:30 pm	Exhibition; Health Physics Society Business Office and Health Physics Society Placement Office will be open	
9:00 am—10:00 am	Session A: Internal Emitters II, Whole Body Counting Studies	Riviera
10:00 am—11:30 am	Bioassay Problems	"
9:00 am—11:30 am	Session B: Surface Contamination and Environmental Radiation Measurements	Thunderbird
11:45 am—2:00 pm	Luncheon and Speaker (members only)	Riviera
2:15 pm—4:45 pm	Session A: Waste Disposal	"
2:15 pm—4:45 pm	Session B: Dosimetry	Thunderbird

Thursday, June 15

9:00 am—5:30 pm	Exhibition; Health Physics Society Business Office and Health Physics Society Placement Office will be open	
9:00 am—11:45 am	Session A: Radiobiology and Ecology	Riviera
9:00 am—11:45 am	Session B: Miscellaneous Topics in Health Physics	Thunderbird
1:45 pm—4:00 pm	General Session: Symposium on Dosimetry	Riviera
4:00 pm—4:45 pm	Business Meeting	"
5:30 pm—6:30 pm	Cocktail Party (members, wives, students and exhibitors)	"
6:30 pm—10:45 pm	Banquet Dinner show (members, wives, students and exhibitors)	"

Friday, June 16

9:00 am—5:30 pm	Exhibition; Health Physics Society Business Office and Health Physics Society Placement Office will be open	Riviera
9:00 am—10:45 am	Symposium on Rover Project	"
10:45 am—12:25 pm	Symposium on Radiation Accidents	"
2:00 pm—4:00 pm	Tours of Las Vegas Laboratories	"

Tuesday Morning, June 13, 1961

General Session — Hotel Riviera, Versailles Room

9:00 am — Welcome and Opening Remarks—John S. Laughlin, President, and H. E. Grier, Health Physics Society

EDUCATION AND TRAINING IN HEALTH PHYSICS

Moderator: W. D. Claus, U. S. Atomic Energy Commission, Washington, D. C.

Dedication—In Memory of Dr. Elda E. Anderson

9:15–12 Existing Training Programs

W. D. Claus, *U. S. Atomic Energy Commission, Washington, D. C.*

Needs in Government

F. J. Weber, *Division of Radiological Health, Dept. of Health, Education and Welfare, Washington, D. C.*

Needs in Industry

E. C. Barnes, *Westinghouse Electric Corp., Pittsburgh, Pa.*

Needs in Medicine

W. Seaman, *Columbia Presbyterian Medical Center, New York, N. Y.*

Objectives of Academic Training Programs

M. Eisenbud, *New York University Medical Center, New York, N. Y.*

International Aspects of Health Physics Training

M. Suzuki, *International Atomic Energy Agency, 11 Kaerntnering, Vienna*

Certification Standards

F. Cowan, *Brookhaven National Laboratory, Upton, N. Y.*

Professional Status for the Health Physicist

W. D. Claus, *U. S. Atomic Energy Commission, Washington, D. C.*

Tuesday Afternoon, June 13, 1961

Session A — Hotel Riviera, Versailles Room

INTERNAL EMITTERS I

INHALATION STUDIES

Chairman: J. N. Stannard, University of Rochester, Rochester, N. Y.

1:45 pm Effect of Particle Size and Total Dose on Retention and Translocation of Inhaled Plutonium

W. J. Bair, *Hanford Atomic Products Operation, Richland, Wash.*

2:00 pm Bronchogenic Carcinoma From Chronic Irradiation with Radioactive Cerium Fluoride ($Ce^{144}F_3$) Particles

H. Cember, *University of Cincinnati, Cincinnati, Ohio*

2:15 pm Translocation and Excretion of Inhaled $Ce^{144}O_2$ Particles

R. A. Hennacy, *Hanford Atomic Products Operation, Richland, Wash.*

2:30 pm Distribution and Excretion of Thorium in the Rat Following Parenteral Administration

R. G. Thomas, R. Lie and J. K. Scott, *University of Rochester, Rochester, N. Y.*

2:40 pm Distribution and Excretion of Thorium in the Rat Following Inhalation

B. B. Boecker, R. G. Thomas and J. K. Scott, *University of Rochester, Rochester, N. Y.*

2:50 pm Discussion

2:55 pm Inhalation of U_3O_8 Smoke from Exploding Wires

B. R. Fish and F. G. Karioris, *Oak Ridge National Lab., Oak Ridge, Tenn. and Marquette University, Milwaukee, Wis.*

3:10 pm Size-Selective Samples for Estimating "Respirable" Dust Concentrations

M. Lippmann and W. B. Harris, *U. S. Atomic Energy Commission, Health and Safety Laboratory, N. Y.*

3:25 pm Discussion

MAXIMUM PERMISSIBLE EXPOSURES

Chairman: Wright H. Langham, Ph. D., Los Alamos Scientific Lab., Los Alamos, N. M.

3:30 pm Variability of Relative Organ Concentration of Trace Elements in Human Tissue

W. S. Snyder and M. J. Cook, *Oak Ridge National Lab., Oak Ridge, Tenn.*

3:50 pm Radionuclide Classification: Relative and Absolute Hazard

J. W. Vanderbeek, *Hanford Atomic Products Operation, Richland, Wash.*

4:10 pm The Estimation of the Internal Radiation Exposure Resulting from the Ingestion of Fallout-Contaminated Water in a Nuclear War

M. B. Hawkins, *University of California, Richmond, Calif.*

4:30 pm Comparison of Predicted and Measured Equilibrium Levels for Chronically Administered Cesium-137

C. R. Richmond, Ph. D. and J. E. Furchner, Ph. D., *Los Alamos Scientific Lab., Los Alamos, N. M.*

Tuesday Afternoon, June 13, 1961

Session B — Hotel Thunderbird, Camellia Room

DEVELOPMENT AND DESIGN OF LABORATORY AND PLANT EQUIPMENT

Chairman: P. B. K'Burgh, E. I. du Pont de Nemours and Co., Inc., Savannah River Plant

Co-Chairman: H. A. McClearen, E. I. du Pont de Nemours and Co., Inc., Savannah River Plant

1:50 pm Radiation Design and the Health Physicist

L. Lewis, *Carolinas-Virginia Nuclear Power Associates, Inc.*

2:04 pm Health Physics Aspects of Handling Spent Fuel Elements at the Savannah River Plant

R. D. Caldwell, *E. I. du Pont de Nemours and Co., Inc., Savannah River Plant*

Tuesday Afternoon Session B Cont.

2:18 pm — Health Physics Considerations in the Design of the Argonne 12.5 Bev Zero Gradient Synchrotron
R. V. Wheeler, *Argonne National Lab., Lemont, Ill.*

2:32 pm — Radiation and Contamination Control Improvements for a Plutonium Processing Plant
W. L. Marter, *E. I. du Pont de Nemours and Co., Inc., Savannah River Plant*

2:44 pm — Safety Performance Testing for Sealed Radioisotope Sources and Devices
P. C. Aebersold, Ph. D. and J. W. Hitch, *U. S. Atomic Energy Commission, Washington, D. C.*

2:58 pm — Control of Contamination in High Level Caves at the Savannah River Laboratory
R. C. Craft, *E. I. du Pont de Nemours and Co., Inc., Savannah River Plant*

3:12 pm — Hazards Associated with Liquid Hydrogen Bubble Chambers
A. A. Weintraub and M. S. Weinstein, *Health and Safety Lab., U. S. Atomic Energy Commission, New York, N. Y.*

3:26 pm — Experience with an Ionization Chamber Pulse Reader at Hanford
F. L. Rising, *General Electric Co., Hanford Atomic Products Operation, Richland, Wash.*

3:40 pm — Radiological Development within the Hanford Radiation Protection Program
C. M. Unruh, *General Electric Co., Hanford Atomic Products Operation, Richland, Wash.*

3:54 pm — Calibration of a Fission Gas Monitor
W. C. Day, R. F. Selden, Ph. D., *Lewis Research Center, NASA, Cleveland, Ohio*

4:08 pm — Radiation Safety Considerations for Subcritical Reactors
R. W. Clack and W. R. Kimel, Ph. D., *Kansas State University*

4:22 pm — Discussion

Tuesday Afternoon, June 13, 1961

Session C — Hotel Thunderbird, Champagne Room

MISCELLANEOUS TOPICS IN HEALTH PHYSICS

Chairman: M. Eisenbud, Professor, New York University Medical Center, Institute of Industrial Medicine

1:45 pm — An Experimental Evaluation of Multiple Crystal Arrays and Single Crystal Techniques
C. E. Miller, *Argonne National Lab., Lemont, Ill.*

2:00 pm — Natural Environmental Radiation Measurements in New York State
W. M. Lowder and A. Shambon, *U. S. Atomic Energy Commission, New York, N. Y.*

2:15 pm — Fallout Strontium-90 in the Human Environment
A. R. Schulbert, *Lamont Geological Observatory, Columbia University, Palisades, N. Y.*

2:30 pm — Sampling Networks for Radioactivity in Air
R. H. Goeke, J. G. Bailey and A. P. Zizos, *Division of Radiological Health, Public Health Service*

2:45 pm — Correlation of Uranium Alpha Surface Contamination, Air-Borne Concentrations and Urinary Excretion Rates
N. B. Schultz, B. F. Shinn and A. F. Becher, *Union Carbide Nuclear Co., Oak Ridge, Tenn.*

3:00 pm — Recess

3:15 pm — The Post Nuclear Attack Water Contamination Problem
W. J. Lacy and M. J. Stangler, *Office of Civil Defense Mobilization*

3:30 pm — An Evaluation of the Health Physics Problems from Thorium and its Daughters in a Thorium Purification and Fabrication Process
C. M. West, *Oak Ridge National Lab., Oak Ridge, Tenn.*

3:45 pm — Radiological Protective Apparel Program at Hanford
T. C. Mehas, *Hanford Atomic Products Operation, Richland, Wash.*

4:00 pm — Criteria for Appropriate Establishment of Removable Radioactive Surface Contamination Limits
G. W. Spangler, *Atomics International, Canoga Park, Calif.*

4:15 pm — Discussion

Wednesday Morning, June 14, 1961

Session A — Hotel Riviera, Versailles Room

INTERNAL EMITTERS II

WHOLE BODY COUNTING STUDIES

Chairman: W. J. Bair, Hanford Atomic Products Operation, Richland, Wash.

9:00 am — Quantitative Measurements of Some Gamma-Ray Emitting Radionuclides in Nuclear Industrial Workers by Whole Body Counting Techniques
F. Swanberg, Jr., *Hanford Atomic Products Operation, Richland, Wash.*

9:15 am — Problems and Methods of Determining ZN-65 in Humans
H. E. Palmer and W. C. Roesch, *Hanford Atomic Products Operation, Richland, Wash.*

9:30 am — The Whole-Body Counting of Persons Involved in SL-1 Reactor Criticality Incident of January 3, 1961
L. L. Skolil, J. I. Anderson and A. Harbertson, *U. S. Atomic Energy Commission, Health and Safety Division, National Reactor Test Station, Idaho Falls, Idaho*

Wednesday Morning Session A Cont.

9:40 am — The Whole-Body Counting of Persons Involved in Silver-110 Incident at the National Reactor Test Station
L. L. Skolil, J. I. Anderson and A. Harbertson, *U. S. Atomic Energy Commission, Health and Safety Division, National Reactor Test Station, Idaho Falls, Idaho*

9:50 am — Discussion

BIOASSAY PROBLEMS

Chairman: R. G. Thomas, M. D., Lovelace Foundation, Albuquerque, N. M.

10:00 am — In Vivo Gamma Spectrometry for Inhalations of Cobalt-60, Neptunium-237—Protoactinium-233 and Zirconium-95—Niobium-95
R. E. Cofield, *Y-12 Plant, Union Carbide Nuclear Co., Oak Ridge, Tenn.*

10:15 am — Accidental Personnel Exposure to Elemental S-35
A. R. Maass, Ph. D., T. L. Flanagan, D. Blackburn and M. Smyth, *Smith, Kline and French Labs., Philadelphia, Pa.*

10:30 am — Puqfua: An IBM-704 Fortran Code for Determining Plutonium Body Burden from Urine Assays
J. N. P. Lawrence, *Los Alamos Scientific Lab., Los Alamos, N. M.*

10:45 am — Studies on Rates of Elimination of Tritium-Labeled Water In Humans
R. Moore and E. R. Buskirk, *American National Red Cross, Washington, D. C.*

11:00 am — Infant Retention Studies
C. P. Straub, Ph. D. and N. C. Telles, M. D., *Robert A. Taft Sanitary Engineering Center, Public Health Service, Cincinnati, Ohio*

Wednesday Morning, June 14, 1961

Session B — Hotel Thunderbird, Camellia Room

SURFACE CONTAMINATION AND ENVIRONMENTAL RADIATION MEASUREMENTS

Chairman: E. Alpen, U. S. Naval Radiological Defense Lab., San Francisco, Calif.

Co-Chairman: H. J. Dunster, United Kingdom Atomic Energy Authority, Harwell, England

9:00 am — Studies of Surface Contamination. 1. Intercomparison of M Methods for Measuring "Removable" Contamination
G. W. Royster, Jr. and B. R. Fish, *Oak Ridge National Lab., Oak Ridge, Tenn.*

9:15 am — A Portable Dose Rate Instrument for Measurement of Natural Background Radiation Levels
F. L. Rising, *Hanford Atomic Products Operation, Richland, Wash.*

9:25 am — The Radiological Safety Program at Indian Point Station
W. F. Nelson, *Consolidated Edison Co., New York, N. Y.*

9:35 am — Surface Contamination Measurements as an Index of Control of Radioactive Materials
H. J. Dunster, *United Kingdom Atomic Energy Authority, Harwell, England*

9:50 am — Limitations of Commercially Available Instrumentation for Analysis of Environmental Media
R. K. Stoms, R. Brueneman and J. Berger, *Public Health Service, Cincinnati, Ohio*

10:00 am — Recess

10:10 am — X-Radiation Surveys of Microwave Generators
W. P. Knox, M. M. Weiss and J. D. Struthers, *Bell Telephone Labs., Whippany, N. J.*

10:20 am — Improvements in Air Sampling Techniques and Equipment Using Membrane Filters
K. J. Schiager, T. M. Allen, S. B. Gerber, G. E. Kinsella, F. J. Krupka and D. W. Reilly, *Argonne National Lab., Lemont, Ill.*

10:30 am — The Radiation Protection Program for a Large Private Utility Power Reactor
J. H. Hughes, *Dresden Nuclear Power Station, Joliet, Ill.*

10:40 am — Radiation Measurements over Simulated Plane Sources
F. J. Davis, Ph. D. and P. W. Reinhardt, *Oak Ridge National Lab., Oak Ridge, Tenn.*

10:50 am — Results of the "Orphee" and "Euridyce" Experiment
F. Duhamel, J. Pradel and M. Gras, *Commissariat L'Energie Atomique, Saclay, Paris, France*

11:05 am — A Summary of Radiation Exposures Received by Workers in Medical Isotope Laboratories and X-ray Departments from 1950–1960
C. K. Spalding and R. F. Cowing, *New England Deaconess Hospital, Boston, Mass.*

11:15 am — Discussion

11:30 am — Adjournment

Wednesday Afternoon, June 14, 1961

Session A — Hotel Riviera, Versailles Room

WASTE DISPOSAL

Chairman: C. P. Straub, Ph. D., Radiological Health Research Activities, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

2:15 pm — The Importance of Verifying Design, Calculations and Assumptions with Measurements in a Stack Monitoring Field-Monitoring Hazards Control Program
L. D. Van Vleck, *General Electric Co., Idaho Falls, Idaho*

2:25 pm — Calculation of the Effective Height of a Plume
M. LeQuinio, *Commissariat l'Energie Atomique, Saclay, Paris, France*

2:35 pm — Health Physics Consideration for the Disposal of Nonenriched Uranium Chips by Burning
M. Sanders, *Y-12 Plant, Union Carbide Nuclear Co., Oak Ridge, Tenn.*

2:45 pm — Discussion

Wednesday Afternoon Session A Cont.

2:50 pm — Routine Measurements of Ground Water Velocity Using Sulfur-35
W. F. Merritt, *Atomic Energy of Canada, Chalk River, Ontario*

3:00 pm — Columbia River Continuous Monitoring System
T. C. Mehas, *Hanford Atomic Products Operation, Richland, Wash.*

3:15 pm — Discussion

3:20 pm — Recess

3:30 pm — Sodium Attapulgite Clay as a Radioactive Waste Disposal Agent
F. Sicilio, N. H. Horton and R. J. Klett, *Georgia Institute of Technology and the Floridin Co., Tallahassee, Fla.*

3:40 pm — Mineral Reactions, A New Waste Decontamination Process
J. F. Honstead, L. L. Ames and J. L. Nelson, *Hanford Atomic Products Operation, Richland, Wash.*

3:55 pm — Cesium Exchange Properties of Vermiculite
D. G. Jacobs, *Oak Ridge National Lab., Oak Ridge, Tenn.*

4:05 pm — Processing by Resins of Radioactive Liquid Effluents of Intermediate Level
M. Cohen, *Commissariat l'Energie Atomique, Saclay, Paris, France*

4:20 pm — Significant Results in Low-Level Waste Treatment at Oak Ridge National Laboratory
K. E. Cowser, *Oak Ridge National Lab., Oak Ridge, Tenn.*

4:30 pm — Strontium Removal from Waste Solutions
T. Tamura, *Oak Ridge National Lab., Oak Ridge, Tenn.*

4:40 pm — Discussion

4:45 pm — Adjournment

Wednesday Afternoon, June 14, 1961

Session B — Hotel Thunderbird, Camellia Room

DOSIMETRY

Chairman: W. S. Snyder, Oak Ridge National Lab., Oak Ridge, Tenn.

Co-Chairman: L. S. Taylor, National Bureau of Standards, Washington, D. C.

2:15 pm — Radiation Yield from Some Bare Critical Assemblies
R. H. Ritchie, Ph. D., H. B. Eldridge and V. E. Anderson, *Oak Ridge National Lab., Oak Ridge, Tenn.*

2:30 pm — Application of Phantoms to Studies of Blood Sodium Activation by Neutrons
J. A. Auxier, F. W. Sanders and W. S. Snyder, Ph. D., *Oak Ridge National Lab., Oak Ridge, Tenn.*

2:45 pm — A Casualty Assessment Device for Measuring Neutron-Induced Body Activity
E. R. Ballinger, M. D., *Los Alamos Scientific Lab., Los Alamos, N. M.*

3:00 pm — Some Convenient Representations for Fission Neutron Distributions in Air
R. L. French, *Convair, Fort Worth, Texas*

3:15 pm — A Comparison of Some Recent Calculations of Neutron Transport in Air
M. B. Wells, *Convair, Fort Worth, Texas*

3:30 pm — An X-Ray Source for Energy Dependence Studies in the 10 to 100 kev Range
R. Sanna and A. Shambon, *Health and Safety Laboratory, U. S. Atomic Energy Commission, New York, N. Y.*

3:45 pm — Scattered Radiation from Large Cobalt-60 Calibrating Sources
L. Costrell, M. S. and H. O. Wyckoff, Ph. D., *National Bureau of Standards, Washington, D. C. (L. S. Taylor presenting paper)*

4:00 pm — A Developer Modification to Increase the Range of Dosimeter Films
H. M. Cleare and N. H. King, *Eastman Kodak Co., Rochester, N. Y.*

4:15 pm — A Miniature 2π Dosimeter
D. E. Hegberg, *Hanford Atomic Products Operation, Richland, Wash.*

4:30 pm — Current Developments in the Use of Nitrous Oxide in the Radiation Dosimetry Associated with the Lockheed Radiation Effects Reactor
R. E. Simpson, *Lockheed Aircraft Corp., Marietta, Ga.*

Thursday Morning, June 15, 1961

Session A — Hotel Riviera, Versailles Room

RADIOBIOLOGY AND ECOLOGY

Chairman: S. P. Hungate, Hanford Atomic Products Operation, Richland, Wash.

Co-Chairman: H. V. Larson, Hanford Atomic Products Operation, Richland, Wash.

9:00 am — Modification of Zinc-65 Absorption by Dietary Zinc
C. R. Richmond, Ph. D. and J. E. Furchner, Ph. D., *Los Alamos Scientific Lab., Los Alamos, N. M.*

9:15 am — Bioaccumulation of Radioactive Isotopes by Herbivorous Small Mammals
S. V. Kaye and T. B. Dunaway, *Oak Ridge National Lab., Oak Ridge, Tenn.*

9:30 am — Reduction of Radioactivity in Milk
R. W. Carter, W. V. Willis and R. H. Fetner, *Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Ga.*

Thursday Morning Session A Cont.

9:40 am — Radiological Surveillance of Total Diets in Selected Locations in the United States
H. F. Kraybill, C. Clavert, W. M. Decker and J. G. Terrill, *Public Health Service, Washington, D. C.*

9:50 am — Strontium-90 Monitoring at the Savannah River Plant
S. E. Butler, *Savannah River Plant, Aiken, S. C.*

10:00 am — Determination of Strontium-90 in Sea Water
H. Francois, *Commissariat l'Energie Atomique, Saclay, Paris, France*

10:10 am — Recess

10:25 am — Semi-Quantitative Relationship of Radiation and Neoplasms in Man
V. E. Archer and L. Simpson, *National Cancer Institute, Washington, D. C.*

10:35 am — An Epidemiological Study of the Effects of Microwaves on the Lens of the Eye
M. Zaret, S. Cleary and M. Eisenbud, *Dept. of Ophthalmology and Dept. of Industrial Medicine, New York Univ. Medical Center, New York, N. Y.*

10:45 am — Dependence of Rate of Recovery from Acute Gamma Ray Exposure on Size of the Conditioning Dose
J. S. Spaulding, Ph. D., T. T. Trujillo and W. L. Lestourgeon, *Los Alamos Scientific Lab., Los Alamos, N. M.*

11:00 am — Multivariate Analysis and the IBM 704 Computer Applied to ABCC Data on Growth of Surviving Hiroshima Children
J. C. Nehamias, *U. S. Atomic Energy Commission, Wash., D. C.*

11:15 am — Discussion

Thursday Morning, June 15, 1961

Session B — Hotel Thunderbird, Camellia Room

MISCELLANEOUS TOPICS IN HEALTH PHYSICS

Chairman: J. R. Horan, Idaho Operations Office, U. S. Atomic Energy Commission, Idaho Falls, Idaho

Co-Chairman: W. H. Kingsley, Sandia Corp., Albuquerque, N. M.

9:00 am — Direct Underwater Maintenance of the GCRE Reactor
W. S. Gault, J. M. Janis and M. K. Wu, *Aerojet-General Nucleonics Co., Idaho Falls, Idaho*

9:15 am — A Monitor for the Prompt Detection of Air-Borne Plutonium
J. Chester, *Brookhaven National Lab., Upton, N. Y.*

9:30 am — A System for Beta Scintillation Counting
G. A. Welford and R. N. Donelson, *U. S. Nuclear Corp., Burbank, Calif.*

9:45 am — A Method of Measuring the Concentration of Argon-41 in Air
L. A. Turner, W. R. Champion and J. A. Mohrbacher, *Lockheed Aircraft Corp., Dawsonville, Ga.*

10:00 am — An Estimation of Radiation Exposure from Fallout
R. Szepke, *Central Laboratory for Radiological Protection, Warsaw, Poland*

10:15 am — Recess

10:30 am — Radioactive Contaminants in the Effluent from the Brookhaven National Laboratory Air-Cooled Reactor
C. F. Foelix, *Brookhaven National Lab., Upton, N. Y.*

10:45 am — Health Physics in a State Health Department
C. E. Roessler and U. Clark, *Florida State Board of Health, Jacksonville, Fla.*

11:00 am — Use of Multi-Channel Analyzers in Health Physics Training
H. F. Steward and C. D. Geilker, *Robert A. Taft Sanitary Engineering Center, Public Health Service, Cincinnati, Ohio*

11:15 am — A Shadow Shield for Whole Body Counting
W. C. Roesch, Ph. D. and H. E. Palmer, *Hanford Atomic Products Operation, Richland, Wash.*

11:30 am — Discussion

11:45 am — Adjournment

Thursday Afternoon, June 15, 1961

General Session — Hotel Riviera, Versailles Room

SYMPOSIUM ON DOSIMETRY

Chairman: K. Z. Morgan, Ph. D., Oak Ridge National Lab., Oak Ridge, Tenn.

1:45 to 4:00 pm

Some General Remarks on Radiation Dosimetry
G. S. Hurst, Ph. D., and R. H. Ritchie, Ph. D., *Oak Ridge National Lab., Oak Ridge, Tenn.*

The Calorimetric Measurement of Local Absorbed Dose
J. S. Laughlin, Ph. D., *Memorial Center, New York, N. Y.*

Pulse Counters for Gamma Dosimetry
A. R. Jones, *Atomic Energy of Canada, Chalk River, Ontario*

Solid State and Luminescence Dosimetry
F. H. Attix, *U. S. Naval Research Lab., Washington, D. C.*

Developments in Radiation Polymerization Dosimetry
F. E. Hoecker, *University of Kansas, Lawrence, Kansas*

Absorbed Dose and Local Energy Density
H. H. Rossi, Ph. D., *Columbia University, New York, N. Y.*

4:00 pm — Business Meeting Health Physics Society

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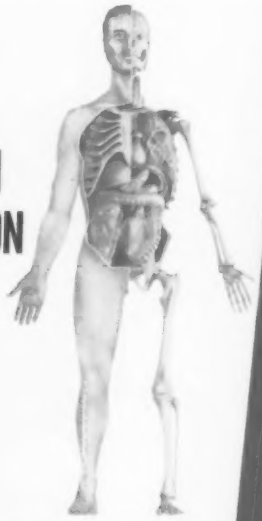

The Radiation Protection Guide is a wall-chart illustration of the human body showing the maximum permissible dosages to the critical organs, skin, etc., as established by the U.S. Atomic Energy Commission. To receive your free copy, just drop us a card stating "RADIATION PROTECTION GUIDE".

VISIT US AT THE HEALTH PHYSICS MEETING IN BOOTH 10

NUCLEONIC CORPORATION OF AMERICA
196 DEGRAW STREET, BROOKLYN 31, N. Y.

Friday Morning, June 16, 1961

Hotel Riviera, Versailles Room

SYMPOSIUM ON ROVER PROJECT

Chairman: H. F. Schulte Los Alamos Scientific Lab., Los Alamos, N. M.

9:00 am — Nuclear Heat Exchanger Rockets
R. S. Cooper, *Los Alamos Scientific Lab., Los Alamos, N. M.*

9:25 am — Radiation Safety in the Development and Use of Nuclear Energy for Rocket Propulsion
W. H. Langham, Ph. D., *Los Alamos Scientific Lab., Los Alamos, N. M.*

9:50 am — KIWI-A-Prime and KIWI-A-Three Radiation Measurement Results
H. S. Jordan, *Los Alamos Scientific Lab., Los Alamos, N. M.*

Friday Morning, June 16, 1961

Hotel Riviera, Versailles Room

SYMPOSIUM ON RADIATION ACCIDENTS

Chairman: E. L. Saenger, M. D., University of Cincinnati

Co-Chairman: N. Wald, M. D., University of Pittsburgh

10:45 am — Graphic Aids in Determining Reactor Hazards in the Event of an Accident
J. C. Couchman, M. A., *Convair, Fort Worth, Texas*

10:55 am — Influence of Continuing Clinical Observations on Dose Estimates One Year After a Radiation Accident
M. Ingram, M. D., J. W. Howland, M. D., C. L. Hansen, Jr., Ph. D., M. D. H. Mermagen, B. S. and C. R. Angel, Ph. D., *University of Rochester School of Medicine & Dentistry, Rochester, N. Y.*

11:10 am — The Radiation Incident at the Sandia Corporation Van De Graaff Facility on November 8, 1960
H. L. Barrick, G. E. Tucker, Jr., W. D. Burnett and W. H. Kingsley, *Sandia Corp., Albuquerque, N. M.*

11:20 am — Medical Aspects of Accidental Exposure to a Van De Graaff Generator
S. P. Bliss, M. D., *Sandia Corp., Albuquerque, N. M.*

11:35 am — Discussion

11:45 am — Health Physics Aspects of the SL-1 Accident
J. R. Horan and W. P. Gammill, *Idaho Operations Office, US Atomic Energy Commission, Idaho Falls, Idaho*

12:00 — Analytical Problems Associated with the SL-1 Accident at the National Reactor Test Site
E. R. Ebersole, *Idaho Operations Office, US Atomic Energy Commission, Idaho Falls, Idaho*

12:15 pm — Discussion

12:25 pm — Adjournment

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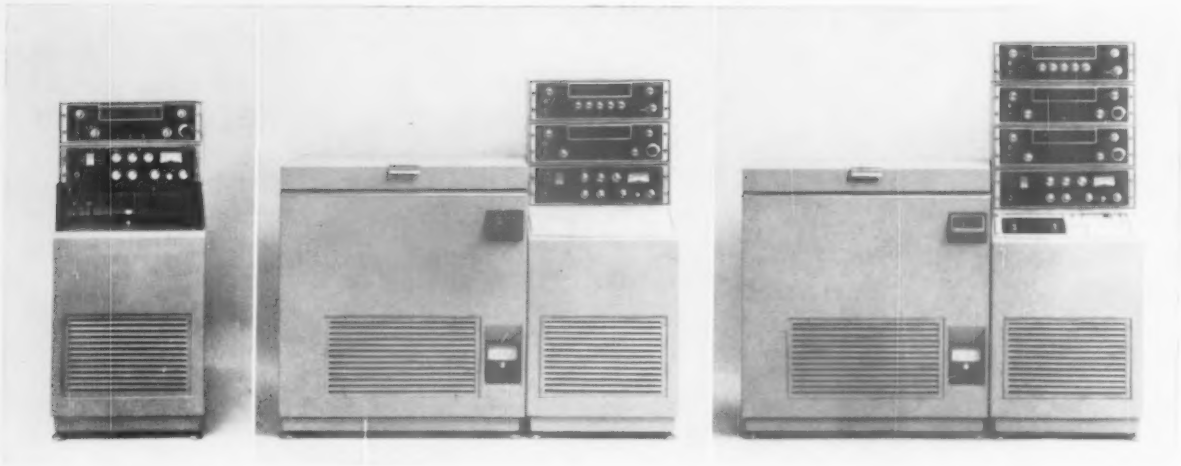

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Start here for economical, room-temperature counting of C^{14} and H^3
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manual operation, shown with 8250 scaler

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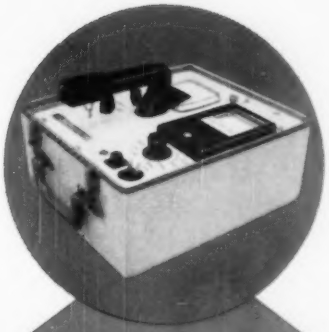

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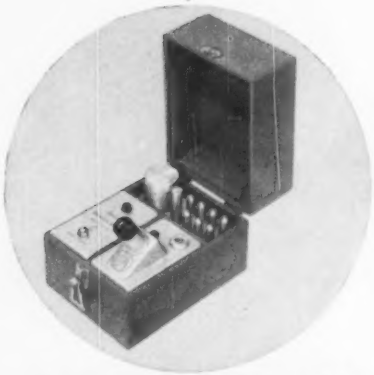

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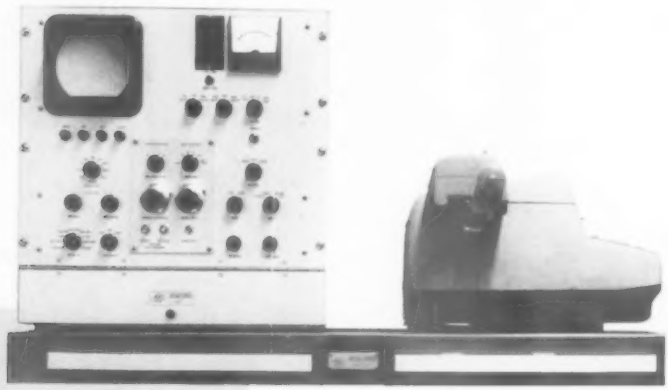

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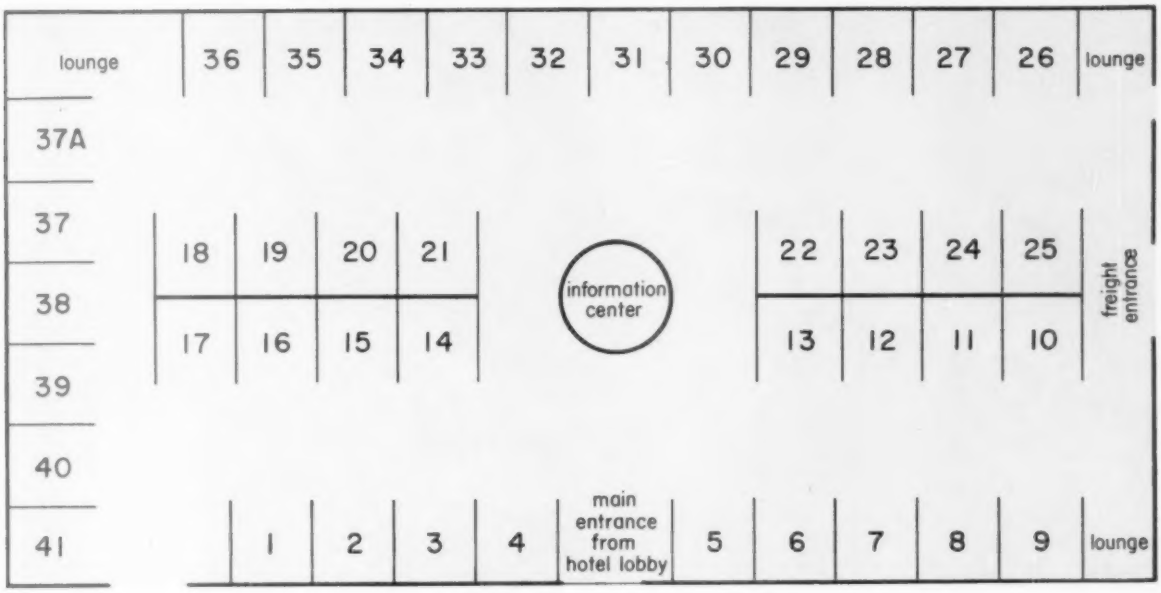

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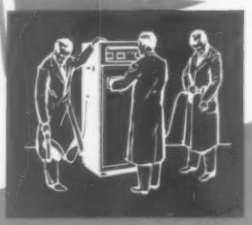

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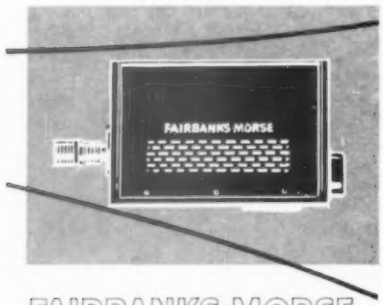

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See advertisement in this program, Page W

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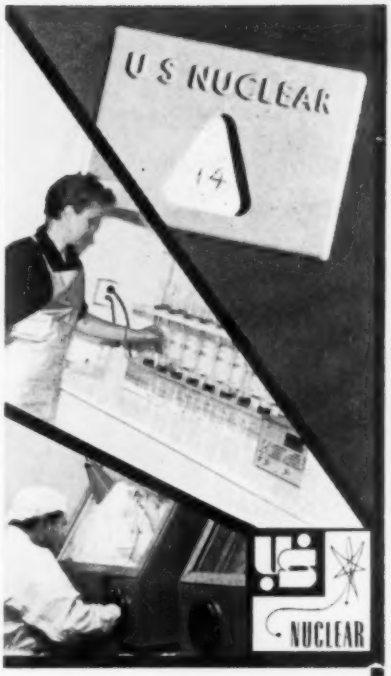
Radiation-measurement instrumentation, travelling-wave oscilloscopes, underwater engineering services, flash tubes, thyratrons, diodes and pulse generators.

See advertisement in this program, Page M



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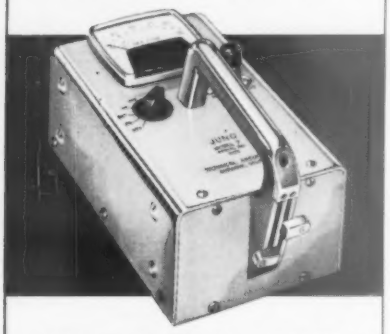

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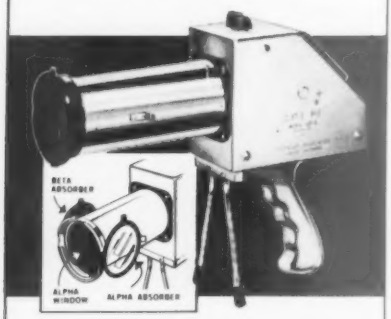

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See advertisement in this program, Page N

Lockheed Nuclear Products 35
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Los Alamos Scientific Laboratory 41
Office of Public and Employee Relations
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475 Washington Ave.
Newark, N. J.

Nuclear-Chicago Corp. 27, 28
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See advertisement in this program, Page L

Nuclear Corporation of America 33
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Radiation monitoring equipment.

See advertisement in this program, Page W

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See advertisement in this program, Page V

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See advertisement in this program, Page O

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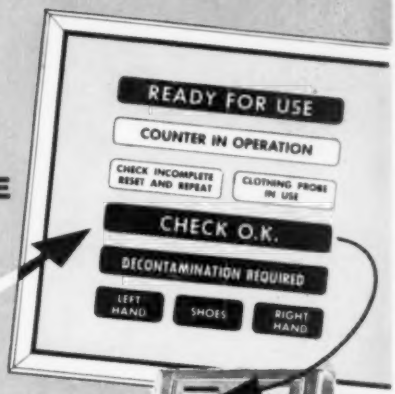

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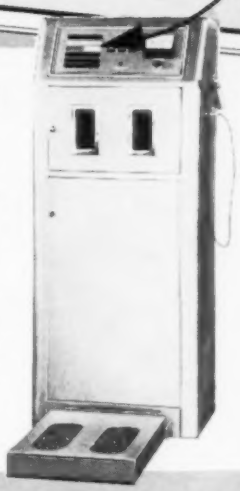

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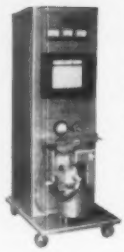

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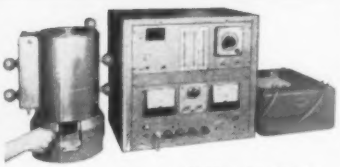

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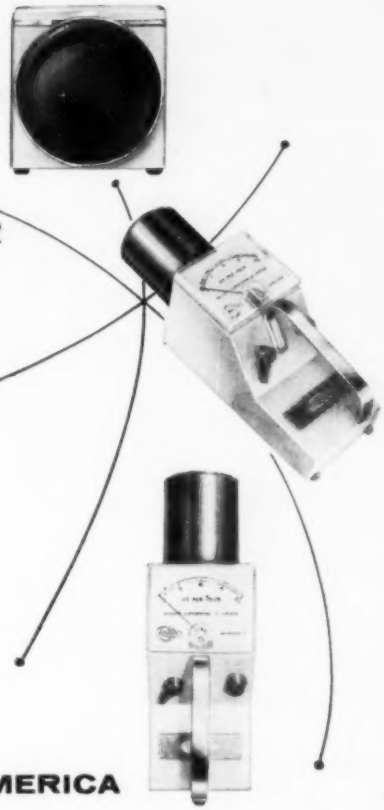

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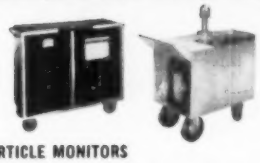

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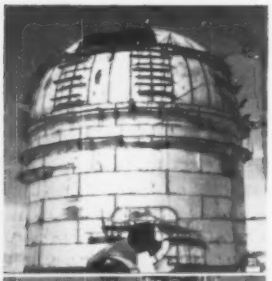

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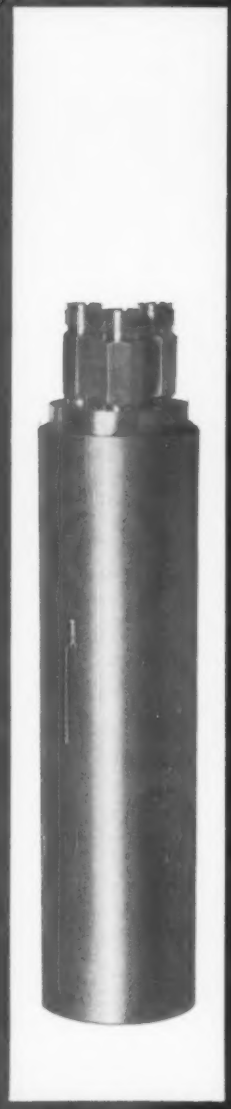

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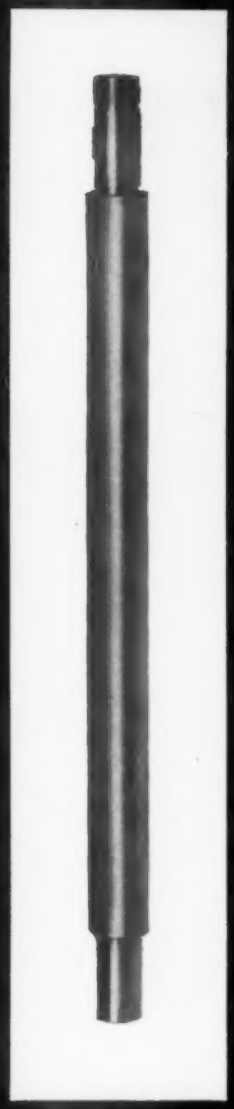

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NUCLEAR ELECTRONIC PRODUCT SECTION

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Microwaves in New Detector Measure Thermal-Neutron Flux

By PRICE D. WICKERSHAM* and LYDICK T. OSTWALD,† *Ramo-Wooldridge, Denver, Colorado*

One way to measure thermal-neutron flux is to let neutrons ionize gas in a waveguide and then observe the resulting phase shift and attenuation in the microwaves passing through the guide. These changes indicate neutron flux.

We have tested this principle both analytically and experimentally with a breadboard model to see if a neutron detector based on the theory would be an improvement over standard ion-chamber methods in speed of response, ambient temperature operation, cost and detector geometry. Although our investigations were limited to an initial determination of the problems, the results show that the neutron detector not only withstands large temperatures, but also has a very fast response. To increase the sensitivity of the detector, however, we find that we must use a relatively pure gas because detector performance depends on the ratio gas pressure to contaminant content.

* PRESENT ADDRESS: Dit-Mco, Inc., Kansas City, Missouri.

† PRESENT ADDRESS: Ball Brothers Research, Boulder, Colorado.

How We Measure Flux

We first subject a length of waveguide containing a neutron-reactive gas and mounted on a breadboard to the flux (*1*). Neutrons pass into the gas and ionize it; this ionization then produces proportionate changes in the complex dielectric constant of the waveguide interior and, therefore, a measurable attenuation and phase shift in the propagated electromagnetic wave. The change in microwave propagation gives ambient neutron flux.

Breadboard. To check our technique and determine any necessary changes in design or fabrication that would give more practical performance we ran our breadboard model through the series of tests in the Curtiss-Wright 1-Mw swimming-pool reactor (Figs. 1 and 2) (*2*). Since the breadboard is a nonresonant, waveguide arrangement in which attenuation is the prime measured variable, it overcomes the limitations of resonant cavities that produce frequency shifts and mode changes.

Waveguide. The sensitive part of the breadboard system is the 24-in. waveguide that contains a Pyrex capsule filled with gas that reacts with neutrons. We filled the Pyrex capsule rather than the waveguide with the gas so that we would reduce experimental difficulties with excessive gas contamination. During the experiments we placed the straight part of the waveguide containing the gas capsule a few inches from the face of the reactor core so that it would receive a large neutron flux. We then passed a 4-kmc/sec microwave signal modulated at 1 kc/sec through the waveguide at a power level of ~0.1 Mw (Fig. 2).

(*Continued*)

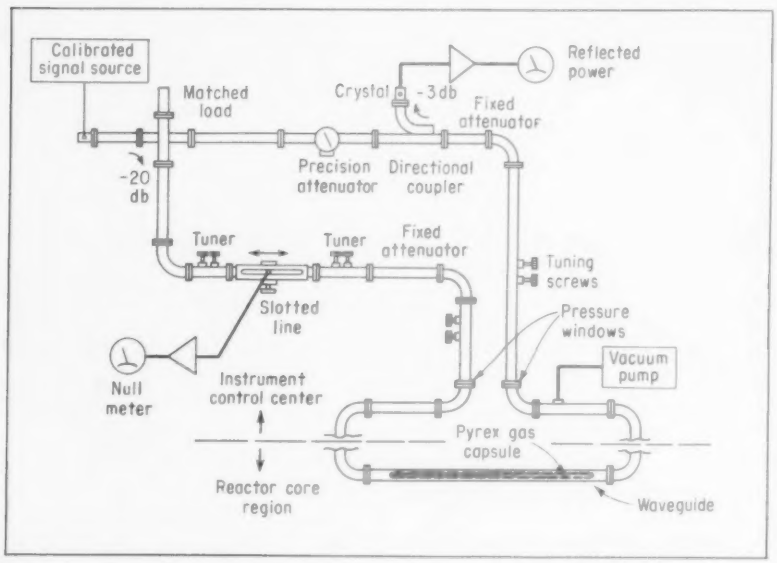
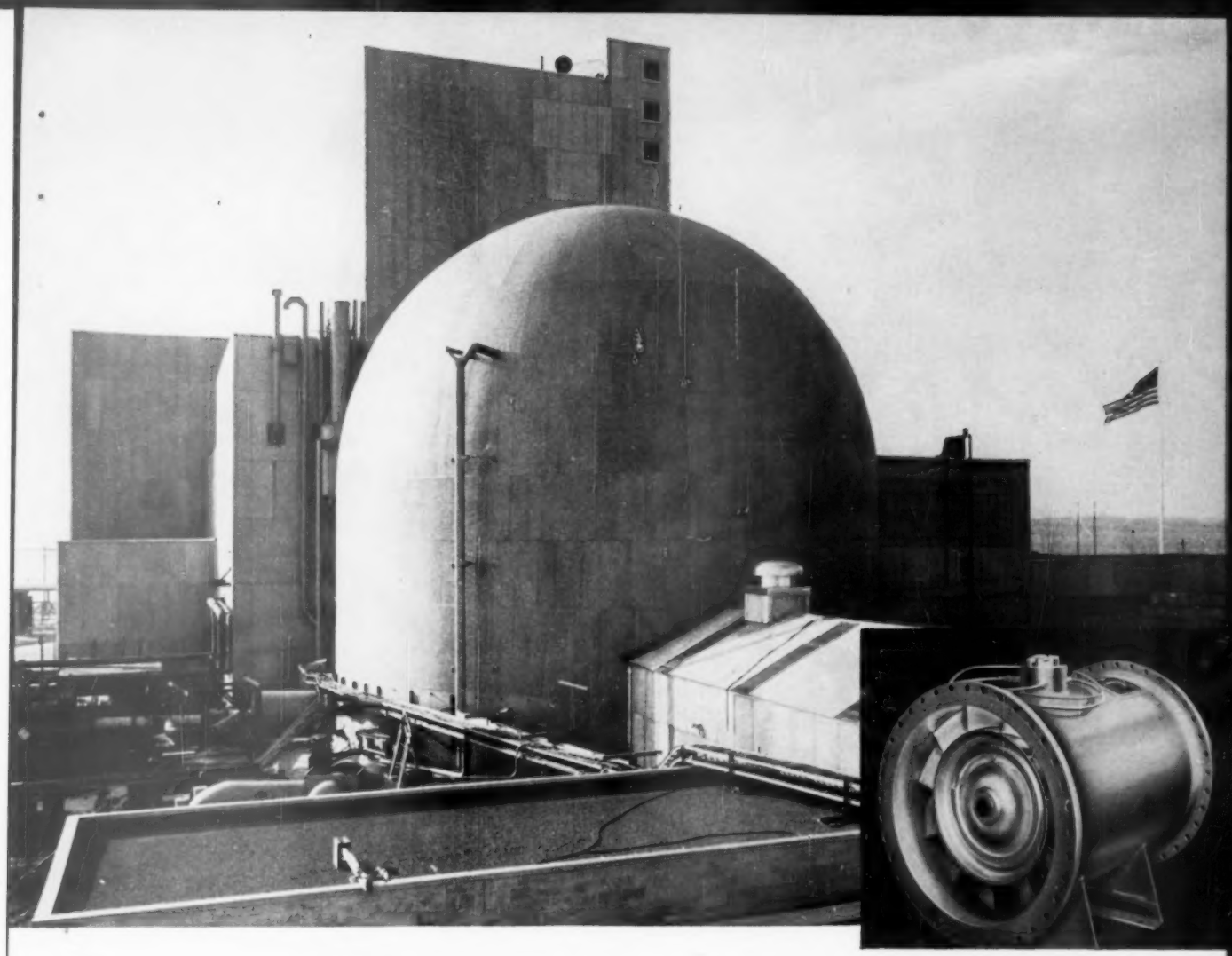


FIG. 1. **BREADBOARD MODEL** contains waveguide with gas-filled capsule. When neutrons react with gas, phase shift and attenuation in microwaves passing through waveguide indicate neutron flux

FIG. 2. **WAVEGUIDE** was tested in Curtiss-Wright 1-Mw swimming-pool reactor to check operation and theory of detector



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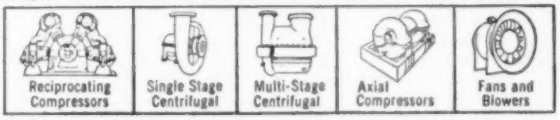

JOY

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Gas for capsule. As the gas for our experimental detector we chose He^3 because it is nontoxic and cannot be easily contaminated with electronegative gases. When neutrons react with He^3 at a 1-atm pressure [He^3 $(n,p)H^3$], the ranges of the triton and secondary proton are ~2.8 and 4.1 cm respectively. Since these distances are similar to the cross-sectional dimensions of usable waveguides, a reduction in gas pressure will reduce ionization rates.

Theory Versus Experiment

Before designing and constructing the experimental system, we made a preliminary analysis to find a basis for selecting such system parameters as frequency, gas type and pressure to predict the attenuation and phase shift that should occur in a rectangular waveguide from a particular incident neutron flux.

In this analysis we determined the production rate of free electrons in the gas as a function of thermal-neutron flux, estimated the free-electron attrition rate, found as a result of these competitive actions the steady-state free-electron density and finally calculated the microwave attenuation and phase shift in the ionized medium with this free-electron density.

Results. Figures 3 and 4 show the results of our calculations and experiments. In Fig. 3 the calculated performance curves, which take into account the effects of gas contaminants, are compared with experimental values. The extremely large contaminant level in the He^3 explains the small values for attenuation and phase shift.

Figure 4 shows the expected microwave attenuation incurred by a 4-kmc/sec signal passing through the "C" band waveguide as a function of incident neutron flux. The figure indicates the effects of contamination and some measure of the improvements to be expected by increased purity.

From these results one can see that the performance of our detector depends greatly on the ratio of gas pressure P to contaminant content C. Thus, even though we have shown that neutron-flux measurements using microwave techniques are feasible, our calculations and experiments indicate that we must use a relatively pure chamber gas to get a sensitive detector.

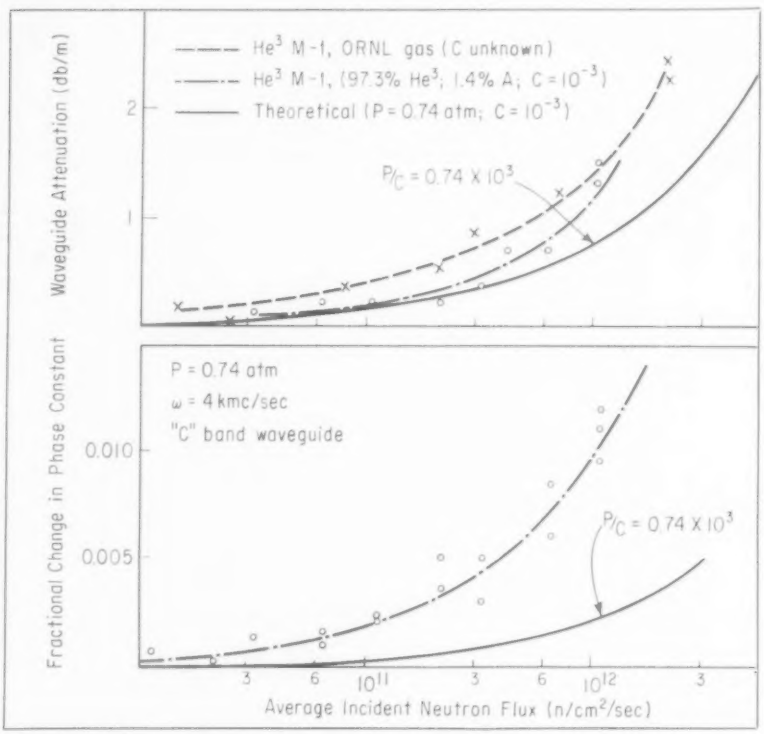

FIG. 3. PERFORMANCE CURVES. Calculated curves (solid) compared with experimental curves (dotted) show results of our work

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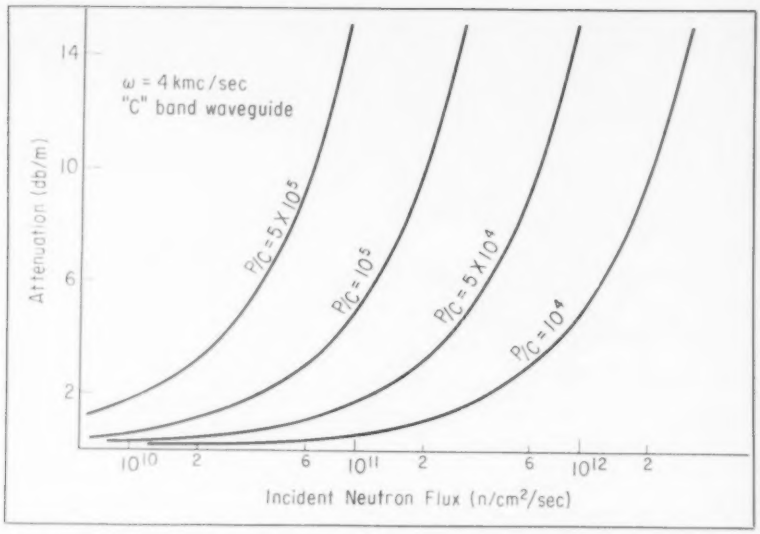

FIG. 4. MICROWAVE ATTENUATION change with flux. Detector performance depends greatly on ratio of pressure to contaminant, P/C

Curve Calculations

The change in the waveguide propagation constants can be related analytically to the incident neutron flux by calculating the free-electron density produced in the waveguide and the corresponding effect on the microwave parameters.

The rate of change of electron density in a given volume element of the chamber is

$$\frac{dn}{dt} = \pi_p + D_a \nabla^2 n - \alpha n^2 - n \sum^{k} H \nu_e$$

(n is free electrons/cm³; π_p is ion pair production/sec/cm³; D_a is bipolar diffusion coefficient, cm²/sec; α is recombination coefficient, cm³/sec; H is electron attachment coefficient—probability that individual electron will attach to gas molecule during elastic collision; ν_e is electron-molecule collision frequency, collisions/sec).

The rate of formation of electron-ion pairs, π_p, depends on the incident thermal-neutron flux, the probability of nuclear reaction in the chamber gas and the amount of ionization produced by the energetic daughter particles. Therefore π_p is a function of the type of filling gas, the gas pressure and the dimensions of the chamber as compared to the path length of the recoil particles in the chamber gas.

$D_a \nabla^2 n$ accounts for the diffusive flow of electrons. The proportionality constant D_a deals with the effects of mobility and charge of the ionization products. Measured values of D_a for electrons in helium are ~60 cm²/sec at a gas pressure of 8.5 mm Hg; this coefficient, however, is a function of the mean electron energy and the gas pressure (*3*). Chamber geometry is contained in the Laplacian operator, which is replaced by appropriate partial differentials depending on the coordinates and boundary geometry of the system.

The recombination rate of free electrons with positive ions is expressed by αn^2. This loss process, which depends on the nearly equal electron and positive-ion densities, is proportional to the square of the electron density. Measured values of α, the recombination coefficient in pure gas, are 10^{-6}–10^{-8}/sec (*4*).

If a small amount of argon is added to very pure helium, the effective volume recombination rate is lowered for electrons in the helium. (Argon is not considered an impurity because it does not contribute to the loss or depletion of free electrons). This effect may result because additional electrons are produced by ionization of argon (*5*).

The summation term in the equation gives the rate at which electrons are lost by attachment to individual electronegative gases in the chamber gas. This loss depends on the probability of attachment per electron-molecule collision and the density of electrons. The collision frequency, ν_e, depends on gas pressure and the fraction of contaminant present.

The probability that free electrons will become attached to molecular ions varies considerably as a function of the mean electron energy. Oxygen and water are two typical molecular contaminants that have large attachment coefficients and are likely to contami-

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Microwaves Measure Flux

This article starts on page 66

nate chamber gases (*6*). At electron energies corresponding to 300° K, measured values of the parameter H for these two contaminants are $\sim 4 \times 10^{-4}$ (*7*).

The coefficients in the equilibrium equation are thus functions of gas pressures, the type of chamber gas and the mean electron temperature. The choice of a chamber gas fixes the rate of electron production from nuclear reactions. By considering the energy decay rate of free electrons, one can estimate the mean electron temperature. This energy decay is caused by elastic collision between ions and electrons over the expected lifetime of an electron before it recombines, attaches to impurities or diffuses to the container walls. Since for reasonable gas pressures the mean electron lifetime is much greater than the time needed for the electrons to slow to thermal energies, the electron energy can be considered approximately that of the gas.

By making some simplifying assumptions, the equilibrium equation can be solved for the electron-density distribution as a function of chamber geometry, gas pressure and contaminant. For a slender container the volume recombination loss rate is much smaller than that from diffusion or attachment. Therefore, the recombination term, αn^2, can be neglected.

The steady-state solution to the equilibrium equation under these conditions becomes

$$n = \frac{\pi_v}{\sum_k^k H\nu_c} \left(1 - \frac{J_0(iKr)}{J_0(iKa)}\right)$$

$J_0(iKr)$ is the Bessel function of the first kind of zero order with an imaginary argument; $K^2 = \sum_k^k H\nu_c/D_k$; a is the mean waveguide radius.

The resulting distribution is nearly constant across the radius of the cylinder but drops sharply to zero at the boundaries. Thus, the calculated density along the centerline of the cylinder can be used to analyze propagation in a waveguide. For rectangular or square cross sections with the same areas, the distribution differs only slightly.

Transient response. By finding a time-dependent solution to the equilibrium equation, one can estimate the transient response of the microwave neutron detector. When one considers only the principle diffusion mode, the

time constant governing the change in electron density to a step change in incident flux is

$$\tau = \frac{1}{D_a\left(\frac{2.40}{a}\right)^2 + \sum^{k} H\nu_c}$$

(constant 2.40 arises from first root of zero order Bessel function of first kind).

By inserting realizable values for the diffusion and attachment coefficients, one gets values for τ between 10^{-4} and 10^{-2} sec; these values indicate that the detector is inherently fast in response.

Microwave reaction with gas. One can combine the calculated values of electron density with expressions for the waveguide propagation constants to obtain the curves of the expected detector performance shown in the figures.

The interaction of microwaves with a gas containing free electrons is calculated from the expression for the complex conductivity or dielectric constant of the ionized gas,

$$\epsilon = \epsilon_0\left[1 - \frac{\omega_p^2}{\omega^2 + \nu_c^2} + \frac{i\omega_p^2(\nu_c/\omega)}{\omega^2 + \nu_c^2}\right]$$

(ϵ_0 is dielectric constant for free space, ω is radian frequency of electromagnetic wave, ω_p is $(ne^2/m\epsilon_0)^{1/2}$, the plasma frequency, where e is electron charge, m its mass and n number of electrons per unit volume) (*8, 9*).

To calculate the attenuation and phase shift in a rectangular waveguide one inserts the expression for the complex dielectric constant of an ionized media in the free-space waveguide propagation equations (*10*). Then the expression for the free electron density, calculated by solving the equilibrium equation, will relate the waveguide propagation constants to the incident neutron flux.

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Pressure-Suppression Dousing Also Traps Iodine

Experiments at Chalk River show that most of the iodine fission products that might possibly be released with the failure of a reactor primary loop could be scrubbed out of the reactor-room air with water. Within five minutes after a steam-iodine mixture is introduced into a volume of air undergoing dousing with water, the iodine concentration in the air falls to about 10^{-4} its initial value.

Chalk River had already provided a water-dousing scheme for the NPD-2 (Nuclear Power Demonstration) reactor to limit the pressure rise in the boiler room in the event of a rupture of any of the high-pressure hot-water lines. The discovery that water dousing will also trap the highly volatile iodine fission products means an extra bonus in safety for NPD-2. Other power reactors with pressure-suppression spray systems will also be able to take credit for this effect.

Following the Canadian philosophy of reactor safety, NPD-2 is designed without a high-pressure container. In the event of a major rupture the first surge of steam would be vented to the outside atmosphere through a duct which seals immediately thereafter. At this early phase of the accident the steam would not yet contain any fission products. Following this purge, the sealed building would be doused with a large volume of water in the form of fog and spray; the dousing serves to hold the subsequent pressure rise within the 4.8-psi limit of the concrete building structure. At the same time the Chalk River experiments show that the water spray will remove the iodine released to the air in the building during this second pressure buildup. The dousing is expected to effect a reduction in iodine air concentration of at least 10^3 and possibly as much as 10^4. Charcoal filters in the air purification system would remove iodine from the air in the 5-min period before the dousing is complete.

Water of any quality (except perhaps superpure water), with *p*H between 5 and 9, has proved uniformly effective in trapping iodine. Raw river water is satisfactory. The corrosion inhibitors, sodium silicate and sodium polyphosphate, do not interfere with the effect.

An acceptable theoretical explanation of how the water reacts with the iodine to bind it in the liquid phase is still lacking.

(L. C. Watson, A. R. Bancroft, C. W. Hoelke, Iodine containment by dousing in NPD-2, AECL-1130, 1960)

A-Bombs—How To Make Your Own

For a total cost of $100-million, a nation bent on joining the "nuclear-bomb club" could put itself into the business of producing nuclear weapons in a period of 5 years or less. This is the estimate made in a report, "The *N*th Country Problem and Arms Control," published by the National Planning Association. The report goes on to say that there are roughly ten or so nonnuclear countries in the world that have the necessary economic and industrial base and that could collect the skilled scientists and engineers needed to transform the basic principles of the fission bomb (by now available from the open literature) into practical hardware.

To drive home its message the report presents enough information to construct the following "do-it-yourself" program for achieving nuclear capability:

- First, set up to produce Pu^{239} instead of U^{235}—it is cheaper than weapons-grade U^{235} and can be produced as a by-product from other operations, such as nuclear-power generation [France has followed this route and Israel may be following it (NU, Feb. '61, 26)].
- You will need 5–10 kg of Pu^{239} per bomb. Figure on 7,000–14,000 Mwd irradiation of natural uranium for each bomb. If you want to make n bombs per year, then this means your production reactor should operate at a power of about $20 \times n$ Mw(th).
- Make sure the irradiation time is kept short enough so that the Pu^{240} content does not get above 1%; otherwise the high spontaneous-fission rate of Pu^{240} could cause troublesome premature detonations.
- Don't skimp on the size of the chemical reprocessing plant; separating the Pu^{239} from the irradiated fuel may turn out to be trickier than you had thought. As a guide, the plant that France built at Marcoule (which can separate 110 kg of Pu per year) occupies a volume of 4×10^6 ft^3 and employs 60 engineers and workmen on a 24-hr schedule.
- For Pu^{239} bombs, the best trigger system is implosion with shaped chemical explosives. You want the shock wave to compress the Pu^{239} core within about a microsecond.
- On detonation a 5–10 kg device designed according to these directions should fission 10–20% of its plutonium and release 10^{14} joules—a yield equivalent to 20 kilotons of TNT.

The NPA report pointed out that a country with a power reactor already in operation could construct its first device in a period much shorter than 5 years, which is the development time postulated for a country starting from scratch. The report predated and, hence, did not mention the recent advances in gas-centrifuge technology that promise to make nuclear weaponry for the beginner even easier and cheaper.

(W. Davidon, M. Kalkstein, C. Hohenemser, The Nth country problem and arms control, National Planning Assoc., Pamphlet 108, 1960)

New Cross Section For Boron

Recent precise measurements at Brookhaven and Oak Ridge of the B^{10} and natural-boron neutron cross sections coupled with new determinations of B^{10} abundance have resulted in changes in both of these quantities for this key nuclear element. The new thermal-absorption cross section for natural boron is 762 ± 3 barns compared with the old value of 755 ± 2 barns. This higher value divided by the newly measured $3,840 \pm 10$ barns for B^{10} gives an abundance ratio for B^{10} of $19.8 \pm 0.1\%$. This ratio is in precise agreement with some recent, very accurate mass-spectrometer measurements.

The new measurements clear up a previous discrepancy: The old B^{10} cross section combined with the old abundance of 18.8% yielded a cross section for natural boron which did not agree with the accepted value of 755 barns.

Mass spectrometer techniques and measurements of relative cross sections of different boron samples detect small differences in the B^{10} abundance in natural boron, depending on the origin of the boron. The boron used for the new measurements of cross section and abundance was the Argonne-Brookhaven standard boron on which there have been cross section measurements some years ago.

(Neutron Cross Section Evaluation Group, Newsletter No. 1, BNL-607-T178, 1960)

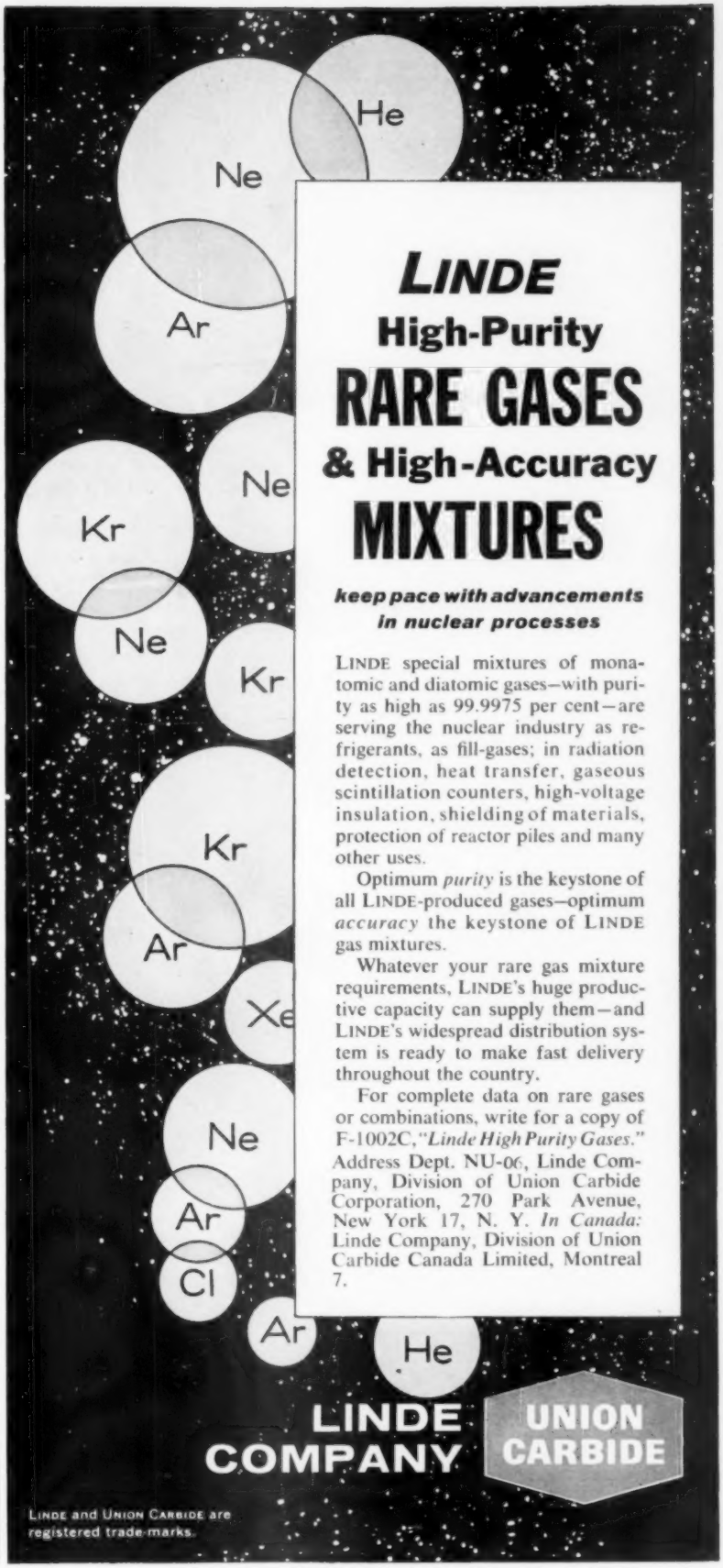
Scanning the Literature

Techniques for X-Ray Diffraction Studies of Radioactive Materials. A description of techniques to minimize the background from radioactive samples undergoing X-ray diffraction studies. (HW-56170—1960)

On the Problem of Liquid Entrainment. Surveys the information available for predicting liquid carry over in a boiling-water reactor at high pressure. (ANL-6244—1960; $2.50*)

Analog Simulation of Xenon Instability. Describes the use of a general purpose analog computer to predict xenon spatial oscillations in a two-group, one-dimensional core. Method gives good agreement with other approaches. (AECL-1185—1961)

* Available from the Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C.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Drag Coefficients for Fuel-Element Spacers

By A. N. de STORDEUR,* *BelgoNucleaire S. A., Brussels, Belgium*

One of the most common reactor fuel geometries is the pin or rod bundle in which coolant flows parallel to the bundle axis. The design of spacers, which prevent pin vibrations and maintain coolant-space dimensions in these bundles, varies from designer to designer but can be divided into two broad categories: spiral spacer wires wrapped around each individual pin and transverse spacer grids of various types (see box).

To predict the pressure drop across these complicated spacer geometries, the core designer adds up three components:

- Pressure loss at core entrance and exit
- Pressure loss across the bundle without spacer
- Pressure loss across the supporting devices.

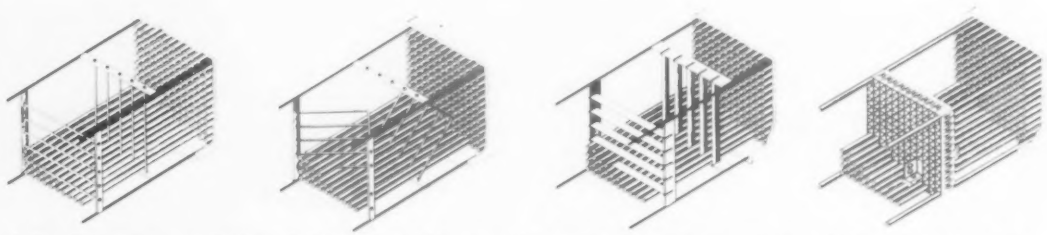
This third loss is most generally calculated from the loss experienced by the coolant as it successively contracts in its passage through the spacer system; one uses the most appropriate abrupt section-change coefficients from Kays and London (*1*), and Moody's (*2*) factor for the friction in the spacing device.

While this method of predicting the spacer loss has given satisfactory results in specific cases of transverse spacer grids (*3*), it has given widely discrepant results in other cases (*4, 5*). It evidently can not be applied to predict the change of pressure drop with pitch in spiral spacer systems since these offer a constant flow section.

We propose a method of calculating the pressure loss due to spacers on the basis of correlations of drag coefficients derived from experimental data. For the three types of transverse grids examined, the expected accuracy of the proposed calculation is within 5–10% of the total pressure loss for the bundle; for spiral spacer wires it is within 10–30%.

Spacer Drag Coefficients

To correlate the experimental pressure-loss data we break down the total test pressure loss, ΔP_T, into the three components already mentioned: ΔP_E



A. Circular wires perpendicular to flow direction

B. Circular-wire "vs" pointed in flow direction

C. Lenticular wires perpendicular (MARV I) to flow direction

D. Honeycomb type grid

FIG. 1. GRID-TYPE SPACER systems tested for pressure drop by Atomic Power Development Associates

The most obvious spacer system is a transverse grid arrangement (Fig. 1a) of circular wires perpendicular to the direction of the flow and attached at each end; consecutive grids are oriented 90° with respect to each other. (In APDA models, grids consisted of 5–6 wires with 2 in. spacing between grids.) High pressure loss of the arrangement led APDA to investigate the effect of grid spacing, inclination of the wire on the direction of the flow, and shape of the grid wires. Inclined wire models (Fig. 1b) led to substantial improvement in pressure drop but showed evidence of nonsymmetrical flow forces acting laterally on the pins. Lenticular-wire prototypes (Fig. 1c) also show marked improvement in pressure drop.

The final spacer type adopted as a reference for Fermi's Core A was the honey-comb-type grid (Fig. 1d) in which the fuel pins are supported symmetrically at four points. Elastic dimples stamped in the metal strips forming the honeycomb structure provide elastic support for the pins.

In contrast to grid supports, is the method of spiral-wire spacers —wires spiraled around each pin maintain proper spacing when the pins are bound together in a bundle. Most spiral-spaced bundles have hexagonal pin arrays in hexagonal container cans. (CVTR and EBR-II models fuel-assembly designs are examples.) However, APDA has considered square arrays of spiral-wire spaced pins.

For the small rod sizes needed in core assemblies the geometry was found to be inherently unstable (due to the effect of accumulated tolerances on the components) and was rejected even though it was attractive from a pressure loss point of view. On the other hand, a square array of large-size rods is compatible with stability conditions, because of the small influence of component tolerances; such an array is used in APDA blanket models.

* Assigned to Atomic Power Development Associates, Inc., Detroit, Michigan, by BelgoNucleaire 1956–60. Present address: Euratom Hdqs., Brussels.

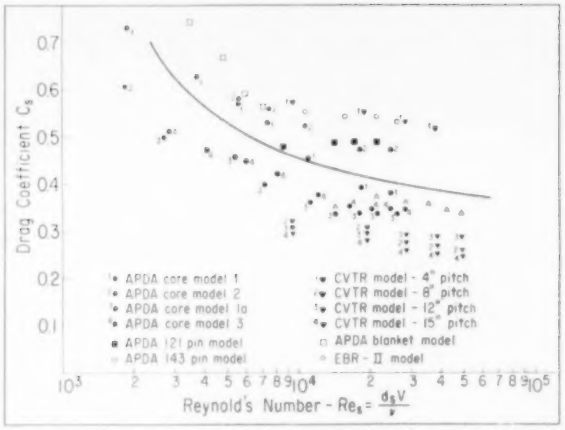

Drag Coefficient C_s
Reynold's Number - $Re_s = \frac{d_s V}{\nu}$
APDA core model 1
APDA core model 2
APDA core model 1a
APDA core model 3
APDA 121 pin model
APDA 143 pin model
CVTR model - 4" pitch
CVTR model - 8" pitch
CVTR model - 12" pitch
CVTR model - 15" pitch
APDA blanket model
EBR - II model

FIG. 2 (ABOVE) DRAG COEFFICIENTS for spiral-wire spacers. Data sources: APDA core and blanket models—Ref. 4; CVTR models—Ref. 10; EBR-II model—Ref. 11; APDA pins—unpl

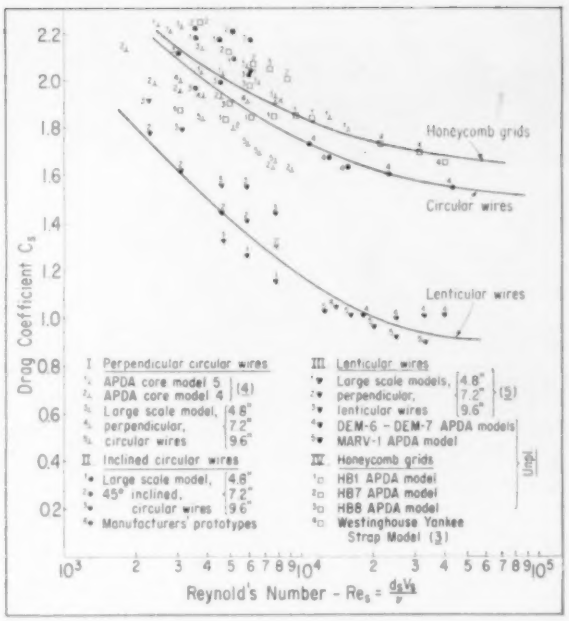

Drag Coefficient C_s
Reynold's Number - $Re_s = \frac{d_s V_s}{\nu}$
Honeycomb grids
Circular wires
Lenticular wires
I Perpendicular circular wires
APDA core model 5 (4)
APDA core model 4
Large scale model, 4.8" perpendicular, 7.2" circular wires 9.6"
II Inclined circular wires
Large scale model, 4.8" 45° inclined, 7.2" circular wires 9.6"
Manufacturers' prototypes
III Lenticular wires
Large scale models, 4.8" 7.2" 9.6" perpendicular, lenticular wires (5)
DEM-6 - DEM-7 APDA models
MARV-1 APDA model
IV Honeycomb grids
HB1 APDA model
HB7 APDA model
HB8 APDA model
Westinghouse Yankee Strap Model (3)
Unpl

FIG. 3 (RIGHT) DRAG COEFFICIENTS for transverse grid spacers. Numbers in parentheses refer to data references. Where no reference is listed (some models in left-hand column), data are from Ref. 5

at bundle entrance and exit, ΔP_R calculated for the rod bundle without spacer and ΔP_S caused by the spacers. We can write

$$\Delta P_S = \Delta P_T - (\Delta P_E + \Delta P_R) \quad (1)$$

For most of the available data, entrance and exit losses have been determined experimentally, and pressure loss obtained over a length of the bundle for the fully established flow conditions. Otherwise, ΔP_E is calculated using abrupt section-change loss coefficients from Kays and London (*1*).

ΔP_R is calculated for the flow unit cell on the basis of the Moody's friction factor (*2*) for a round pipe of the same equivalent diameter and surface roughness.

To calculate a drag coefficient C_S from the experimentally determined ΔP_S we write an expression for the equilibrium of forces on the fluid across the spacer device:

$$\Delta P_S = \frac{C_S V_S^2 S}{2gA} \quad (2)$$

- C_S is the spacer drag coefficient to be correlated from the preceding definition
- V_S is the velocity in the spacer region in ft/sec
- A is the unrestricted flow area in the bundle (away from spacer) in ft²
- S is the spacer projected frontal area in ft²
- g is the gravitational acceleration in ft/sec².

This definition of C_S is similar to classical drag coefficients defined for flow around a body located in an infinite fluid stream. In a similar way, C_S is correlated as a function of a Reynolds number based on the spacer frontal dimension. The velocity in the expression for the Reynolds number is taken equal to that in the spacer region.

Experimental Correlation

Drag coefficients, as defined by Eq. 2, were calculated for all the flow-model tests on which the author could obtain data. The collection included a wide variety of both spiral-wire and transverse-grid-spaced models, ranging from 19 to 144 pins or rods per subassembly, most of which have been tested at APDA.

The first step in the calculation procedure was to establish the flow distribution among the coolant passages of the bundle from the geometrical characteristics. Then for the flow in the center cell of the bundle the pressure loss owing to rods ΔP_R is computed from Moody's friction factor. Subtracting ΔP_R from the total experimental pressure loss ΔP_T gives the pressure loss due to the spacer system ΔP_S. With ΔP_S determined, the drag coefficient can be obtained from Eq. 2, in which the projected spacer frontal area S is calculated from the spacer geometry; for spiral-wire spacers, it is taken equal to the number of spiral turns over the bundle length times the area of an annulus with thickness equal to the spacer-wire diameter. These experimentally derived drag coefficients are plotted versus Reynolds number for spiral-wire spacers in Fig. 2 and for transverse grids in Fig. 3. (The Reynolds number is calculated on the basis of the wire diameter.)

For the spiral spacers the calculated points for each model generally fall on a smooth curve. On the other hand, the spread from model to model covers a relatively wide area. This variation can have different origins: an error in friction factor entering ΔP_R that varies from model to model but is consistent within any single model, the influence of the spiral wire pitch on the perturbed flow region (see above), and experimental error in ΔP_T.

In the absence of a more systematic investigation of this spacer type, the curve in Fig. 2 (the arithmetic average of the calculated point upper and lower envelopes) represents the best estimate of drag coefficients available for design calculation. The spread in the data is 40% of the coefficient value.

As with the spiral-spacer curves, the curves of Fig. 3 for the transverse spacers represent averages between upper and lower-point envelopes for each spacer.

The results for grids of circular wires, both perpendicular and inclined to the flow direction (Figs. 1a and 1b), are correlated by a single curve, independent of the wire angle. This was necessary because of the overlap of the points for these models. In one of the models tested (DEM-4) the wires had different inclinations within the same grid. Its pressure-loss characteristics were identical with the systems using a unique 45° inclination of the wires. The

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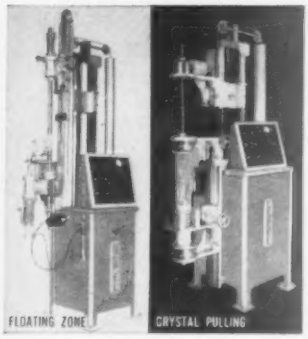

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higher pressure loss (compared to the inclined systems) for the perpendicular circular wire spaced bundles is explained by the greater restriction of velocity.

Drag coefficients for lenticular* wires (Fig. 1c) are lower than for circular wires because of better streamlining of the trailing edge. Large scale models with special streamlined wires (shaped as a circular wire on their upstream face and as a lenticular wire on their downstream portion) showed a pressure loss identical to that of the lenticular wires.

The correlation curve for the honeycomb grid (Fig. 1d) is slightly higher than for circular spacers. It includes results for the three APDA models (with and without elastic dimples) and the strap model of the Yankee fuel element. The correlation proves to be independent of the height of the strips constituting the honeycombs $^3/_8$ in. for HB1, $^1/_2$ in. for HB7 and HB8, and 1.1 in. for Yankee model); this indicates that the pressure drop is mostly a form loss rather than a friction loss.

The drag-coefficient curves proposed for these three spacer types correlate the data to within 15%.

Pressure-Loss Calculation

The curves of Figs. 2 and 3 will allow designers to obtain reasonable estimates of the total pressure drop for proposed spacer systems. The curves agree with the empirical data for drag coefficient to within 40% for helical spacer wires, and to within 10–15% for the transverse spacer grids. Since the pressure loss caused by spacers represents from 30–70% of the total pressure loss, calculations based on these curves will yield accuracies of 10–30% for spiral-wire bundles and 5–10% for grid bundles.

This precision is generally satisfactory for preliminary reactor design work which would then be confirmed by experiments on the actual reference design. New data, as they become available, will permit improvements in the accuracy of the proposed method and lead to new curves relative for other types of spacers. The method for calculating the pressure loss follows the reverse order of that given above for obtaining the experimental correlation of drag coefficients.

Let us go through a sample application for spiral-spacer wires. Suppose that the pressure loss has to be calculated for the following conditions:

- 121 pin bundle on a square pitch
- d, pin diameter = 0.193 in. = 0.0161 ft
- d_s, spiral wire diameter = 0.025 in. = 0.00208 ft
- p, pin square pitch = 0.2205 in. = 0.00208 ft [$p \neq (d + d_s)$ because of oversized can. Clearance between bundle and the can is assumed equally distributed between pins, because of the slightly wavy shape of the pins]
- L, length of pin bundle = 2 ft
- h, helical spacer wire pitch = 0.5 ft
- fluid = water at 190° F ($\nu = 3.6 \times 10^{-6}$ ft² sec).

Flow distribution. The first step is to work out the geometrical constants that determine the flow distribution within the bundle:

- n_1, number of peripheral coolant cells associated with per half pin = 42 (40 half peripheral pins + 4 quarter corner pins)
- n_2, number of central coolant cells = 100
- A_T, total flow area = 16.61×10^{-3} ft²
- De_T, total equivalent diameter = 8.6×10^{-3} ft
- A_C, area of central flow cell without spacer wire = $p^2 - \frac{\pi}{4} d^2 = 1.344 \times 10^{-4}$ ft²
- A'_C, area of central flow cell with spacer wire = $A_C - \frac{\pi}{4} d_s^2 = 1.3104 \times 10^{-4}$ ft²
- De_C, equivalent diameter of central flow cell without wires = $\frac{4A_C}{\pi x_4} =$ 0.01064 ft
- De'_C, equivalent diameter of central flow cell with wire = $\frac{4A'_C}{\pi(d + d_s)} =$ 0.009183 ft
- A_W, area of peripheral flow cell with spacer wire = $p\left(d_s + \frac{d}{2}\right) - \frac{\pi}{8}(d^2 + d_s^2) = 8.271 \times 10^{-4}$ ft²
- De'_W, equivalent diameter of peripheral flow cell with spacer wire = $\frac{4A'_W}{p + \frac{\pi}{2}(d + d_s)} = 0.00705$ ft.

The division of flow rate between periphery and center flow cells is (supposing the friction factors to be equal)

$$\left[\frac{Q_W}{Q_C} = A'_W{}^2 De'_W / A'^2_C De'_C\right]^{\frac{1}{3}} = K_1 =$$

* Double convex shape.

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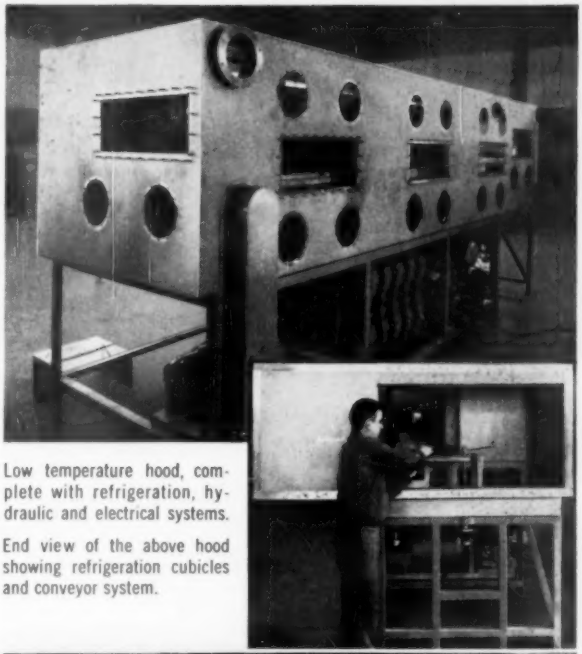

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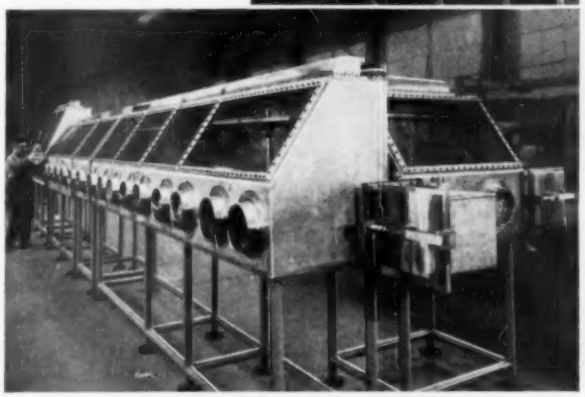

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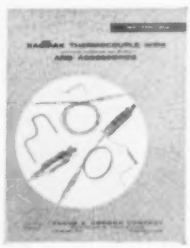

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0.553. We have $A'_W/A'_C = K_2 = 0.631$ and total flow rate $Q_T = n_2Q_C + n_1Q_W$ or $Q_W = (n_2 + n_1K_1)Q_C = 123.226\,Q_C$. The total flow area $A_T = n_2A'_C + n_1A'_W$, which yields $A'_W = (n_2 + n_1K_2)\,A'_C = 126.506A'_C$. Finally we get for the velocity in the central flow cell $V_C = \frac{Q_C}{A'_C} = \frac{Q_T}{A_T} \times \frac{n_2 + n_1K_2}{n_2 + n_1K_1} = \frac{Q_T}{A_T} \times 1.035$.

Loss without spacers. The pressure loss due to the rods, ΔP_R is found by applying Darcy's formula in the spacerless channel for the center channel velocity and corrected for the reduction of area due to the wire presence:

$$\Delta P_R = \frac{f}{2g} L \frac{V^2_C}{De_C} \frac{A_C}{A'_C}$$

here f is taken from Moody's correlation for the Reynolds number

$$Re_R = \frac{De_C}{2} \frac{Q_C}{A'_C}$$

For the two-ft-long 121 pin model and for 190° F water

$$\Delta P_R = f \times Q_T^2 \times 1.1482 \times 10^3$$
$$Re_R = Q_T \times 1.785 \times 10^5$$

Spacer pressure loss. The pressure loss due to the spiral-wires spacers is computed from ΔP_S, by the drag formula

$$\Delta P_S = \frac{C_S}{2g} \left(\frac{Q_C}{A'_C}\right)^2 S \frac{1}{A'_C}$$

where S is the spacer projected frontal area (one annulus of one spacer diameter thickness per turn of the spiral)

$$S = \pi(d + d_s)d_s \times \frac{L}{n}$$

The drag coefficient C_S is found from Fig. 2 for a value of Reynold's number

$$Re_s = \frac{d_s}{\nu} \times \frac{Q_C}{A'_C}$$

Finally, we combine the two terms to get the total pressure drop

$$\Delta P_T = \Delta P_R + \Delta P_S$$

The table lists the values of the significant variables as a function of total flow.

Friction factor. The total friction factor shown in the table is calculated from $f_T = \frac{\Delta P_T A_T{}^2 2g De_T}{LQ^2_T}$ and plotted versus Reynolds number

$$Re_T = \frac{De Q_T}{\gamma A_T}$$

For the 121 pin model, $f_T = 7.65 \times 10^{-5} \frac{\Delta P_T}{Q_T{}^2} Re_T = 1.538 \times 10^5 Q_T$.

Expected accuracy. To estimate the expected accuracy of the calculation, we can write

$$\frac{d(\Delta P_T)}{\Delta P_T} = \frac{d(\Delta P_R)}{\Delta P_T} = \frac{d(\Delta P_S)}{\Delta P_T}$$

Since we assumed $d(\Delta P_R)$ equal to zero in the correlation method, and $d(\Delta P_S)/\Delta P_S = 0.4$ in Fig. 3, we have

$$\frac{d(\Delta P_T)}{\Delta P_T} = 0.4 \frac{\Delta P_S}{\Delta P_T} = 0.4 \frac{\Delta P_S}{\Delta P_R + \Delta P_S}$$

For the 121 pin model, expected accuracy $\sim 12\%$.

Discussion of Assumptions

Since the formula for calculating the drag coefficient is crucial to the method, some remarks concerning the assumptions implicit in this calculation are appropriate. Our definition of C_S includes form and skin fraction losses on the spacer body (as with the infinite-medium drag coefficient), as well as friction losses on the pins entrapped in a transverse spacer grid. This latter

Spiral-Spacer Pressure-Loss Calculation

Q_T (ft³/sec)	0.223	0.3345	0.446	0.5575	0.669
Q^2_T	0.04973	0.11189	0.19892	0.31081	0.44756
Re_R	39,800	59,700	79,600	99,500	119,000
f	0.021	0.0195	0.0185	0.0178	0.0172
ΔP_R (ft)	12.0	25.05	42.25	61.4	88.4
Re_S	8,000	12,000	16,000	20,000	24,000
C_S (from Fig. 2)	0.49	0.44	0.42	0.405	0.395
ΔP_S (ft)	5.3	10.65	18.1	27.2	38.2
ΔP_T (ft) Calculated	17.3	35.7	60.35	88.6	126.6
ΔP_T (ft) Experimental	16.8	36.4	62.04	94.2	134.8
f_T (calculated)	0.0266	0.0244	0.0232	0.0218	0.0216
Re_T	34,400	51,600	68,800	86,000	103,200

contribution to ΔP_S could not be dissociated from the other two by a simple calculation (i.e., the length of the passages in a transverse grid is generally so short that flow regime cannot be fully established and Moody's friction factors are not applicable).

Insufficient information about losses in the pipe inlet region is available to permit predictions in the complicated spacer geometry.

The method supposes that the friction losses over the largest part of the length of the rods and container walls are the same with and without the presence of the spacer system and that these losses can be calculated under the assumption of a fully established flow regime; the method neglects any disruption of the boundary layer by the spacers and changes of flow direction within the bundle are therefore neglected.

That a correlation based on this assumption yields satisfactory results is evidence that the disturbed region is really quite small compared with the fully established regime—for transverse spacers the distance between successive grids is always several orders of magnitude larger than the equivalent diameter. For spiral spacers the validity of the assumption is less obvious.

As might be expected, the calculated drag coefficients show a larger spread for spiral wires than transverse grids.

Tests conducted at APDA demonstrated the negligible influence of the perturbed region in the transverse grid systems. The tests were for two types of spacers that supported the pins in every other row in the same plane (Fig. 1a and 1c). The pressure loss was first obtained for a model with equal longitudinal spacing between grids; then the models were dismantled and the grids rearranged longitudinally by groups of two, as close to each other as grid construction would permit. The restricted flow area in the grid region remained unchanged in the new arrangement and the wires of the two grids grouped together did not obstruct each other. Pressure losses for the new arrangements were similar to those obtained for equal grid spacing.

The calculation of ΔP_R as explained above, implies two simultaneous assumptions:

- The flow rate in the flow unit cell can be calculated from flow distribution based on the geometrical characteristics (area and equivalent diameter) of peripheral and central coolant cells
- Moody's friction factor (*2*) is applicable.

The first assumption is contradicted by some velocity distribution tests performed at APDA on certain types of subassembly prototypes furnished by the fuel manufacturers: Velocity traverses measured with pitot tubes indicate flow maldistribution ($\pm 30\%$), which varies, furthermore, according to the longitudinal position of the probe in the bundle. No explanation has been found for these velocity distribution results, which are disregarded in this paper.

The second assumption has been found in excellent agreement with experimental results. Pressure loss determined at APDA on a bundle section deprived of intermediate supports falls within 5% of that predicted from Moody's friction factor both on full-scale and enlarged-scale models. Other data (*6*, *7*) confirm the assumption; in one other instance (*8*), the experimental data indicate an increase of 65% over Moody's law, which has been attributed to (unmeasured) surface roughness by the authors. Theoretical investigation (*9*) on systems of rods with characteristics (ratio of pin array pitch to pin diameter) close to those considered here yields an expected friction factor in good agreement with Moody's laws.

* * *

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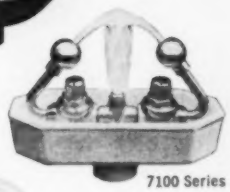

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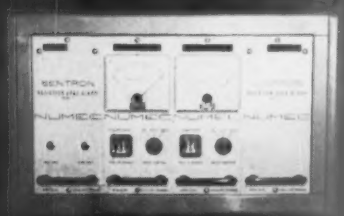

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FIG. 1. AUTOMATIC TESTER measures size of U grains in Hanford fuel slugs before they are canned. Attenuation of ultrasonic pulses beamed through slug measures grain size as slugs are moved (1,000 rpm rotation, 1.4 in./sec translation) through tester. With 2,000 pulses/sec, 12,000 pulses traverse each slug. Defective slugs are rejected automatically; data records tell process trends so corrections can be made as needed

Inspecting Uranium Slugs at Hanford Ultrasonically

By DANIEL C. WORLTON

Hanford Atomic Products Operation, General Electric Co., Richland, Washington

To reject unacceptable fuel elements and control the manufacturing process, we nondestructively test the fuel materials at several stages during the manufacturing process. Because we fabricate a large number of fuel elements, it is important that our inspection equipment be integrated into our automated production lines.

Before we clad our fuel slugs we test them for grain size and any cracks or defects (Fig. 1). We also are developing a test for grain orientation.

The Hanford Slug

The Hanford process fuel element is a uranium cylinder (about 1½ in. in diameter and 8 in. long) encased in and bonded to an aluminum jacket 45 mils thick. To prepare the uranium for canning, we cast it as 6-in.-dia ingots, roll it at 620° C to form rods of nearly the final diameter. Then we machine these to final size. To provide an additional cooling surface, we drill an ~⅜-in. hole along the central axis of some fuel rods so they can be cooled both internally and externally.

Importance of grain orientation. The rolling process preferentially aligns the orthorhombic uranium crystallites lengthwise along the rods. Thus as-rolled uranium is highly anisotropic and would be markedly unstable

dimensionally when it is irradiated.

To improve dimensional stability, we heat-treat the metal to make the crystal orientation random. This transformation process involves heating the metal into the beta phase and quenching it into the alpha. During transformation the metal grains grow to nearly five times their original size, increasing from ~0.035 mm to 0.18 mm or larger. Thus the presence of small alpha grains in a heat-treated fuel core indicates its transformation is incomplete and the crystal preferred orientation will make the fuel dimensionally unstable when irradiated. On the other hand, excessively large grains (~0.35 mm or larger) tend to grow preferentially and form severe "bumps" on the fuel surface. Thus we want the uranium grains to have an average diameter of 0.1–0.35 mm.

Inspecting for Grain Size

To insure that the grains of the fuel cores are within the size range 0.1–0.35 mm, we nondestructively inspect each core ultrasonically before canning it. This test uses the principle that ultrasonic waves passing through a metal are scattered by the periodic grain structure. The degree of scattering (and attenuation) depends mainly on the ultrasonic wavelength and the average grain diameter G; Fig. 2 shows an empirical curve relating these factors for uranium.

Longitudinal ultrasonic waves propagate in uranium at a rate of $\sim 1.33 \times 10^5$ in./sec, so a 5-megacycle test frequency gives a λ/G ratio of ~19 before transformation and 4 after. Figure 2 shows that this corresponds to at least a tenfold increase in attenuation. Thus presence of small alpha grains in a fuel core is detectable ultrasonically because they attenuate the waves measurably less than larger grains do.

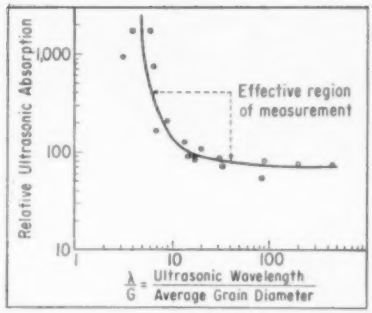

FIG. 2. ULTRASONIC ABSORPTION curve for uranium shows that attenuation is a good measure of grain size for λ/G values less than about 30

Equipment. Figure 3 shows a block diagram of the equipment we developed for this test. Figure 4 shows how the amplitude of a 5-Mc/sec pulsed ultrasonic beam (traversing the core along a transverse section slightly displaced from the axial hole) relates directly to the size of the grains. Although the output voltages measure relative grain size, for calibration we use reference voltages produced by standard cores of known grain size.

By using high-speed recording equipment that records the digital data from the voltmeter we can detect undesirable trends in quality and correct the production process quickly, thus reducing our reject rate. Figure 1 shows the automatic test station.

Core Integrity Test

Included in the automatic grain-size-measuring equipment are circuits that simultaneously assure that each fuel core is free of surface cracks, striations, seams or other defects that would affect reactor performance adversely. This test, developed to supplement (or possibly replace) a visual examination, uses a single crystal to direct the ultrasonic beam at a 75-deg angle with respect to a surface normal. We found experimentally that echo amplitude varies with defect depth (within the range 0.001–0.020 in.) to a degree that permits us to discriminate against shallow, acceptable defects. Echo pulses are electronically counted as the cores are rotated and translated past the test head to provide a total number that measures the integrated length of defects whose depth exceeds the preset limit.

Grain-Orientation Tests

Measurement of average grain diameter only indirectly indicates crystal preferred orientation. We would rather have a nondestructive test that would measure directly the kinds and degree of preferred orientation.

Resonant-frequency method. Since the elastic constants of uranium crystals are directionally dependent, preferential alignment of crystals causes a change in ultrasonic wave velocity. Much effort has gone into developing test methods based on this principle (*1*). One promising technique measures total volume velocity by observing the frequencies at which cores resonate in the longitudinal and torsional modes. The resonant frequencies of Hanford fuel cores are approximated well by

$$F_L = \frac{n}{2L}\left[\frac{E}{\rho}\right]^{1/2}$$

$$F_t = \frac{n}{2L}\left[\frac{G}{\rho}\right]^{1/2}$$

(*Continued*)

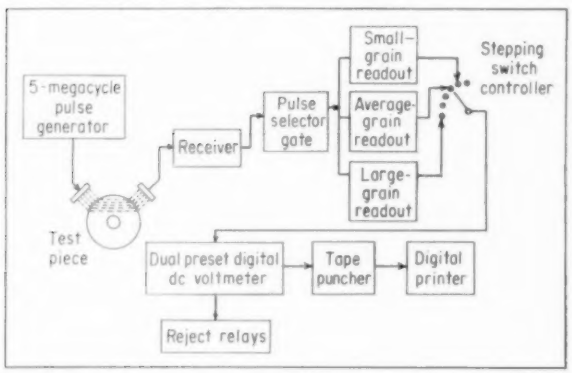

FIG. 3. PULSES ATTENUATED by grains of U slug are amplified in receiver and fed into circuits that show grain sizes; voltmeter converts signals to digital form for reject circuits that separate defective cores from production line

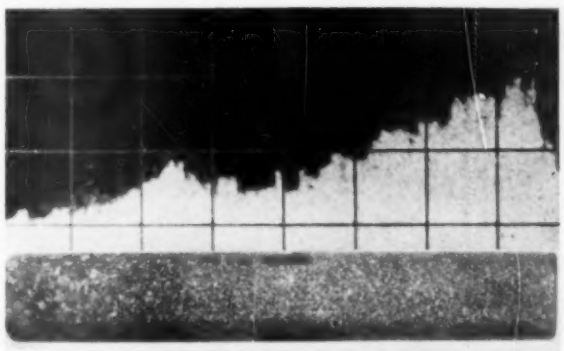

FIG. 4. LARGE GRAINS (toward left end of sample) attenuate an ultrasonic beam more than small grains do, as is shown by this wave trace of pulse amplitude vs. axial position along a fuel core having widely varying grain structure

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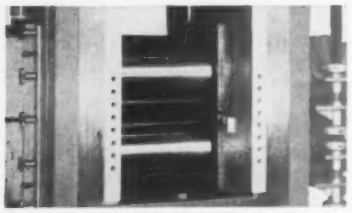

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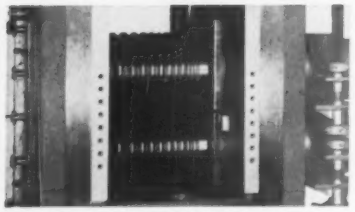

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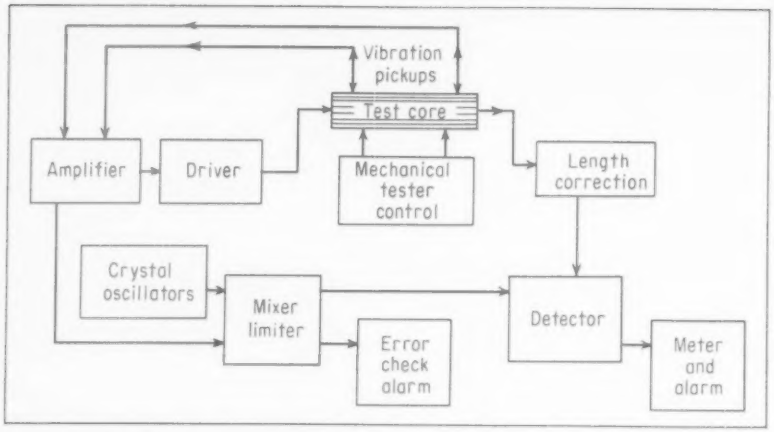

FIG. 5. RESONANT FREQUENCY of ultrasonic waves passing through a U slug indicates grain orientation directly. In equipment outlined here, U slug being tested serves as frequency-determining element in oscillator loop where sharp cut-off band pass filters suppress undesired modes of vibration; output from drive amplifier feeds to frequency counter, from which resonant frequencies are determined

where F_L and F_t are longitudinal and torsional resonant frequencies, L is length, n is mode order, ρ is density, and E and G are Young's and shear moduli. These expressions assume isotropic, homogeneous material; their validity for measuring deviations from this ideal in uranium fuel cores is, of course, questionable. But we believe that preferentially aligned grains would change the effective moduli, and so would change the resonant frequencies.

Using the equipment in Fig. 5, we have seen marked differences in resonant frequencies of cores known to have preferentially oriented grains. Measments on several thousand cores have shown that the method recognizes differences among rods of the same parent metal that have different fabrication histories. Although the technique is a potentially powerful tool for detecting grain orientation, the effects of metal composition, density variations, and residual stresses influence readings to a degree that is difficult to evaluate.

Comparison with X-ray diffraction. The resonant-frequency method has been substantiated somewhat by comparing it with X-ray diffraction data (*2*). The lack of complete agreement in these is not surprising since X-rays are affected only by the material near the surface, while resonant-frequency measurements apply to the total fuel volume.

Comparison with irradiation effects. Our studies suggest that pre-exposure resonant-frequency measurements do indicate in-reactor dimensional stability. A recent test divided 600 fuel cores into three nearly equal groups according to the ratio of longitudinal-to-transverse resonant frequencies. Group A contained F_L/F_t ratios of 0.7794–0.7811, Group B ranged 0.7786–0.7787, and Group C ranged 0.7708–0.7778. Dimensional measurements made before and after irradiation showed that cores in Group C changed size more that did cores in the other groups. For example, after the same exposure the average incremental diameter change for cores in Group C was ~16% larger than it was for cores in Groups A and B; the average warp in Group C was ~18% larger than in the other groups. No significant differences were observed between Groups A and B.

We hope that these data will lead to a nondestructive grain-orientation test that can be written into fuel specifications. We plan a larger test to explore this possibility fully.

* * *

A future article will describe Hanford tests used to determine bond and cladding integrity of the completed fuel elements.

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Thermal Conductivity of UO_2 Improves at High Temperatures

By J. LAMBERT BATES

Hanford Atomic Products Operation, General Electric Co., Richland, Washington

The thermal conductivity of UO_2—a parameter most crucial to the design of high-performance reactor fuel—shows promise of a significant improvement at the high temperatures required to achieve superior performance. This favorable situation stems from our expectation that radiant energy transfer will begin to make a sizeable contribution to the thermal conductivity above ~1,400° C. The existing reliable measurements of UO_2 thermal conductivity show that it falls with increasing temperature as $A/(B + T)$* (the expected behavior for lattice conduction); however, these measurements extend only to 1,100° C (*1–3*). Designers of UO_2 fuel who need estimates of conductivity in the temperature region up to 3,000° K (i.e., the UO_2 melting point) have either used an extrapolation of the reciprocal curve $A/(B + T)$ or, for simplicity, assumed a temperature independent conductivity of 0.0125–0.0208 watt-cm/° C.

Experimental evidence suggests that the thermal conductivity above 1,400° C may be significantly greater than these extrapolated values. Laboratory investigations of unirradiated UO_2 at temperatures to the melting point have established the characteristic temperatures at which certain changes (for example, grain growth, sublimation and crystal growth) occur (*4, 7*). By observing similar physical changes (*8, 10, 20*) in post-irradiation specimens, one can deduce the temperature profile (see Fig. 1 and appendix) during irradiation and from this obtain an estimate of thermal conductivity. Such estimates lead to values larger than those now commonly assumed at temperatures greater than 1,400° C.

The thermal conductivities of a number of metal oxides (for example, MgO, Al_2O_3, BeO) exhibit the same pattern—the conductivity deviates from the

* T is the absolute temperature and A and B are constants.

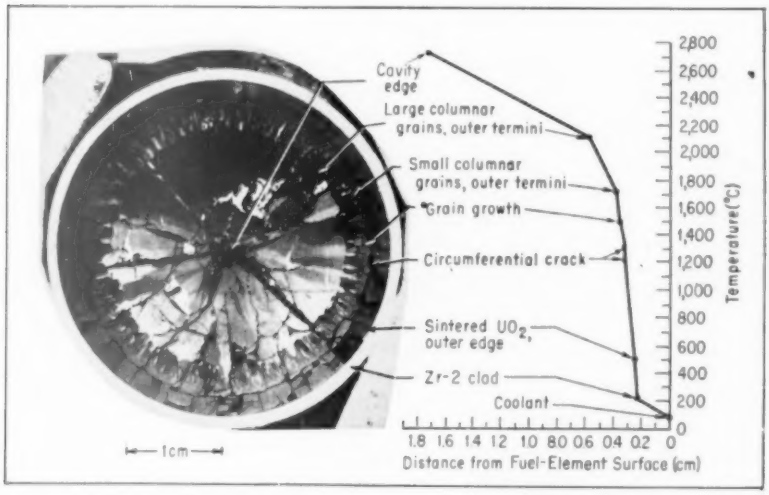

FIG. 1. CROSS SECTION view and radial temperature profile of UO_2 fuel core during irradiation. Heat generation rate was 124 watts/cm³ or 1,180 watts/cm; surface heat flux was 99 watts/cm²; UO_2 density before irradiation was 10.2 gm/cm³ and ratio of O to U 2.02. Temperatures obtained experimentally (see Appendix) check larger UO_2 conductivity predicted by author at high temperature

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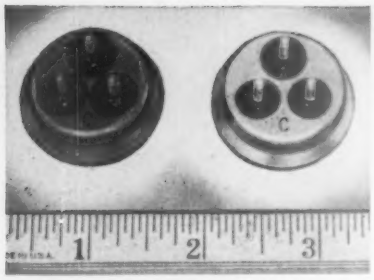

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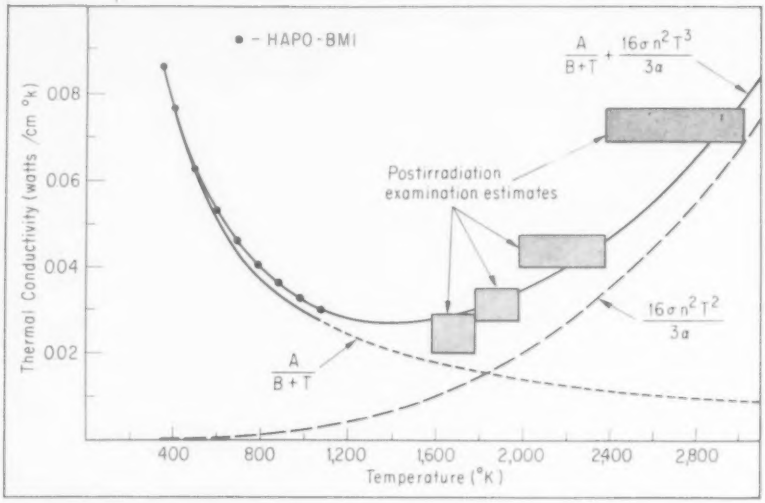

FIG. 2. THERMAL CONDUCTIVITY of UO_2 versus temperature. Solid curve is predicted sum of lattice $[A/(B + T)]$ and radiation $(16\ \sigma\ N^2T^2/3\alpha)$ contributions

reciprocal-temperature relationship at high temperatures (*11–14*).

Investigators have attributed this deviation to the transmission of radiant energy through translucent solids. Similarly, radiant heat transfer in transparent glasses is often 50 times as great as that due to lattice conductivity (*15*). Since Ackermann (*16*) has demonstrated the translucence of UO_2 in the near infrared, we can postulate that radiant transfer in the infrared causes an enhancement of UO_2 conductivity at high temperatures.

Below we derive an equation representing the thermal conductivity of uranium dioxide between room temperature and the melting point that takes into account both lattice conduction and radiant heat transfer. This expression predicts (Fig. 2) that the thermal conductivity passes through a minimum near 1,400° C and increases to approximately room-temperature values at the melting point. Data from the post-irradiation examination of fuel elements support this prediction.

The higher thermal conductivity means that heat-generation rates of UO_2 fuel elements, previously calculated on the basis of $k_{UO_2} = f(T^{-1})$ or k_{UO_2} = constant, can be increased without exceeding core-temperature limits.

Radiation Heat Transfer

The thermal conductivity due to radiant energy transmission through a solid of infinite thickness is given by (*17*)

$$k_r = \frac{16\sigma n^2 T^3}{3\alpha}$$

k_r = Effective thermal conductivity due to radiation, (watt-cm/° K)
σ = Stefan-Boltzman radiation constant (5.6686×10^{-12} watt/cm²/° K⁴).
n = Index of refraction
T = Temperature (°K)
α = Optical absorption coefficient (cm^{-1}).

Ackermann, et al (*16*) has recently reported values for the index of refraction and the extinction coefficient, $\varkappa$, up to 0.8 μ $\left(\varkappa = \frac{\alpha\lambda}{4\pi}\right.$ where λ = wavelength, cm$\left.\right)$. Absolute values of $\varkappa$ were measured to 0.65 μ with upper limits measured to 0.8 μ. The modal wavelength, λ_m (the wavelength for which the monochromatic emissive power is a maximum) is 1 μ at 3,000° K. If we assume this modal wavelength represents an average of the transmitted radiation, Eq. 1 becomes:

$$k_r = \frac{4\sigma n^2 T^3 \lambda_m}{3\pi\varkappa}$$

Thus we can obtain an approximate solution by extrapolating $\varkappa$ to 1 μ. In the extrapolation, we can see the limits of $\varkappa$ at 0.8 μ inasmuch as they represent the maximum values of $\varkappa$. Therefore,

the use of the upper limits of $\varkappa$ results in minimum possible values of k_r. At 1 μ, we estimate in this way that $\varkappa$ is 5×10^{-4} and n is 2.3.

The temperature dependence of n and α for UO_2 is not known. Monroe (*20*) has shown that the average absorption coefficient for Al_2O_3 increases with temperature. The temperature variation was a function of the wavelength of the transmitted radiation with the smallest variations at wavelengths less than 4 microns. In addition, the absorption coefficient increased with temperature up to 1,608° C; above 1,608° C the absorption coefficient for Al_2O_3 did not increase.

Similarly, no published data exist on the temperature variation of the index of refraction for refractive oxides. However, the Lorentz-Lorenz formula for the optical dielectric constant predicts the index of refraction of the oxide should increase with decreasing temperature.

Because no data are available for the temperature variation of the index of refraction and absorption coefficient for UO_2 and data for other refractive oxides are limited, we assume that α and n are constant over the entire temperature range.

A factor that may significantly influence the thermal conductivity in UO_2 fuel elements is the presence of large, radially-oriented columnar grains. These grains may influence the transfer of heat in two ways: (a) The absence of grain boundaries and the presence of high density UO_2 will increase the lattice contribution of the thermal conductivity. (b) The optical density of the large single crystals is smaller than for polycrystalline UO_2 which enhances the contribution of radiation conduction. For example, absorption coefficient of polycrystalline Al_2O_3 is approximately 6 times greater than for single crystals of Al_2O_3. This results in a six-fold increase in the radiation portion of the thermal conductivity in the single crystal. An analogous increase in both the absorption coefficient and the thermal conductivity can be expected for UO_2.

Total Conductivity

The total thermal conductivity of sintered UO_2 is the sum of radiation conductivity k_r and lattice conductivity k_l

$$k = k_l + k_r$$

or

$$k = \frac{A}{B + T} + \frac{16\sigma n^2 T^3}{3\alpha}$$

If we insert the measured values of k_l (*4, 8*) and the extrapolated values of α and n in k_r, Eq. 4 becomes

$$k = \frac{30}{10 + T} \cdot \frac{\rho}{\rho_0} + 2.55 \times 10^{-12} T^3$$

ρ/ρ_0 is the ratio of the specimen density to the theoretical crystallographic density.

The observed effects in the irradiated, sintered UO_2 fuel element (*10*) shown in Fig. 1 support the validity of Eq. 4. Characteristic temperatures (*9, 10*) can be assigned to regions and boundaries by analogy to similar phenomena observed during laboratory experiments at known temperatures in nonirradiated UO_2 (*4–8*). Through these methods (see appendix) we assigned temperatures to the UO_2 cross section in Fig. 1 to obtain the radial profile of UO_2 temperature during irradiation shown there.

From this temperature profile we estimated thermal conductivity values for the regions above 1,500° C. These thermal conductivity values are shown in Fig. 2 in conjunction with the low temperature BMI-HAPO measurements, superimposed on a plot of Eq. 4. Equation 4 closely agrees with the thermal conductivity deduced from the temperature profile of the irradiated fuel element.

* * *

The author wishes to thank Dr. W. E. Roake for his helpful suggestions and advice.

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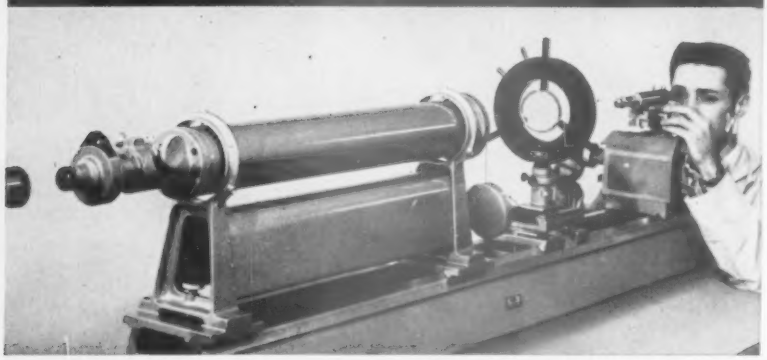

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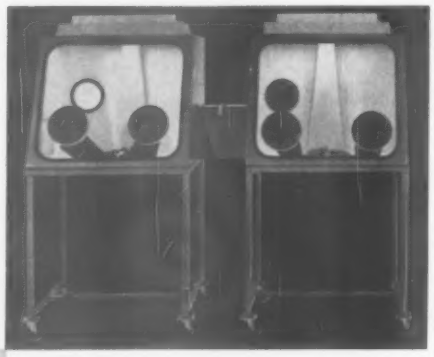

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UO_2 Conductivity

This article starts on page 83

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APPENDIX

Temperature Profile Determination

We estimated the temperatures in the UO_2 during the irradiation in the following manner:

Coolant temperature (45° C): Measured by thermocouples inserted in the coolant water. Thermocouples also indicated the heat generation of the fuel element in conjunction with the coolant flow rate.

Zircaloy cladding temperatures:

- *Outside surface* (115° C): Calculated from the flow characteristics of the flow channel and the fuel-element heat generation.
- *Inside surface* (300° C): Calculated from the temperature drop across the 0.090-cm-thick cladding based on a thermal conductivity of 0.107 watt/cm°C for Zircaloy-2.

UO_2 Temperature at circumferential crack* (1,300° C): In-pile measurements of the effective thermal conductivity and gap conductance of metal-clad UO_2 made by Cohen (*18*) yielded a gap conductance of ~0.1 watt/cm°C for a 0.0025-cm initial gap clearance with a helium atmosphere. For the thermal conductivity these measurements gave an effective value of 0.031 watt/cm°C for a 10.2 gm/cm³ sintered UO_2 fuel core at 500° C. With these values, we obtained a UO_2 surface temperature of 415° C and a temperature at the inside surface of the circumferential crack of 1,300° C.

Alternatively the temperature between the inside Zircaloy surface and the circumferential crack can be estimated from recent thermal conductivity data of irradiated

* Whether the circumferential crack was actually present during the irradiation has been a matter of dispute. However, recent irradiation test results (*19*) from nonsintered, swaged UO_2 fuel rods reveal a crack in the mechanically-bonded, but nonsintered UO_2. This implies that the temperature of the circumferential crack during the irradiation was below the sintering temperature of UO_2, and the circumferential crack would not heal during the irradiation.

UO_2 (*3*). For a helium-filled cladding-UO_2 gap and circumferential crack we calculated:

- *UO_2 surface temperature* (450° C): Calculated for a 0.0025-cm hellium-filled gap between the Zr-2 and the UO_2 during irradiation and helium thermal conductivity = 0.0023 watt/cm°C.
- *UO_2 temperature at outer surface of circumferential crack* (1,200° C): Calculated from HAPO-BMI data (*3*); $k = \frac{35}{T + 350}$ (T in ° C and k in watt/cm°C).
- *Inner surface of circumferential crack in UO_2* (1,300° C): Calculated for a 0.0025-cm, helium-filled gap and helium thermal conductivity = 0.0031 watt/cm°C.

Formation temperature of large equiaxial UO_2 grains (1,500–1,600° C): Sintering experiments have shown large grains, roughly the same dimension along all three axes, form between 1,500–1,600° C over a long sintering period (*6, 7*).

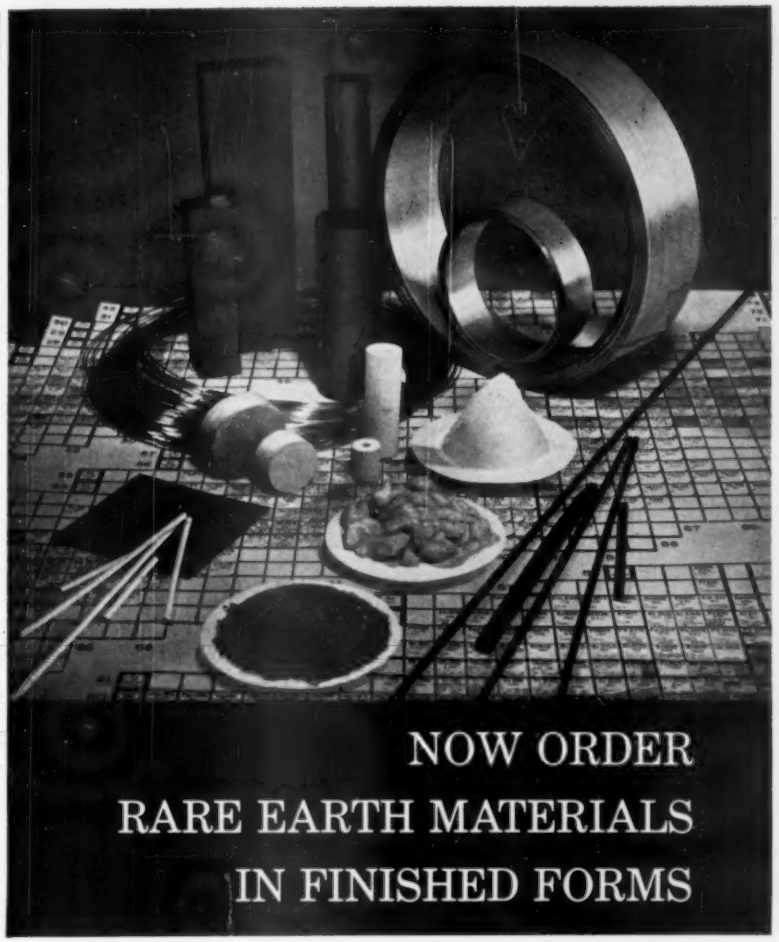
Temperature outer termini of small columnar grains (1,700° C): During laboratory thermal simulation experiments, columnar grains of UO_2 have formed at temperatures as low as 1,700° C (*4–7*).

Temperature outer termini of large columnar grains (2,100–2,200° C): By analogy, the temperature of the outer termini of the large columnar grains is related to observed changes in the crystal growth habits of UO_2 crystals grown from the vapor phase during laboratory tests at 2,100–2,200° C (*4–7*). This temperature is assumed to be the temperature at the intersection of the small and large columnar grains.

Temperature at edge of central cavity (2,700° C): The maximum temperature of the UO_2 at the edge of the central cavity is estimated to be below the melting point. We arrived at this estimate by judging the appearance of the central cavity and the surrounding UO_2 on the basis of our observation of a large number of irradiated specimens of UO_2 fuel. This prior experience has enabled us to distinguish between a truly molten UO_2 fuel core and a fuel core in which the central temperature was below the melting point. The characteristics of the UO_2 core molten during irradiation are:

- The central cavity is irregular and the surface is rough and porous.
- The central cavity is surrounded by extensive columnar grains of UO_2.
- The UO_2 that was molten during the irradiation is composed of large equiaxial grains of UO_2 containing large spherical voids. This sponge-like UO_2 is located inside the central cavity and is attached to the edge of the central cavity in localized areas only.
- The UO_2 in the columnar grains adjacent to the edge of the central cavity contains small voids. The grain boundaries of the columnar grains adjacent to the cavity are irregular.

In contrast, high-temperature UO_2 cores that were not molten (see Fig. 1) during irradiation have round central cavities with smooth internal surfaces. The surrounding columnar grains are relatively free of voids with straight columnar grain boundaries. The central cavity is void of UO_2. Therefore, we estimate the maximum possible temperature at the edge of the central cavity in Fig. 1 to be just below the melting point, i.e., approximately 2,700° C.



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Irradiation Ship Would Eliminate Grain Loss to Insects in Tropics

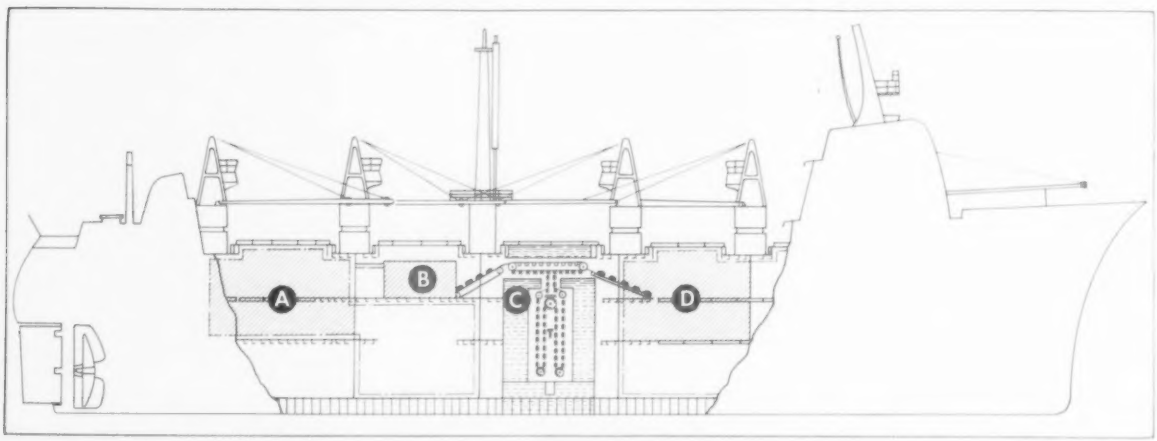
In some parts of the world grain can be stored for at most nine months after harvesting before it is totally consumed by insects. Even in the U. S. with the most modern methods of chemical fumigation losses of stored grain to insects are as high as 50% per year. Lloyd Brownell (University of Michigan) and Tom Horne (Curtiss-Wright) have proposed that an ocean-going ship with a cobalt source in its hold could help reduce the enormous loss of grain to insects in places where grain is most hungered for. They envision a specially equipped grain-irradiator ship that would tour the world, calling upon the ports of food-scarce countries where it would irradiate grain supplies to rid them of insects before they are put into storage.

Irradiation would be much more effective and also cheaper and safer than the chemical fumigation methods now used for this purpose. In the present methods, insecticides kill all the adult insects and larvae that are in grain before it is put in storage, but they do not kill the insect eggs present at the time. This means the stored grain must be refumigated at regular intervals. In northern climates fumigation every 12 or 13 months suffices, but in tropical climates the rate must be increased to every 2 or 3 months. Even at this frequency fumigation does not control some types of insects found in the tropics.

Irradiation, on the other hand, kills both the insects and their eggs. Hence if the grain were irradiated in insect-proof containers, the stored grain would remain free of insect damage for an indefinite period of time. This unique advantage of irradiation processing over chemical methods offers for the first time a practical means of insect control in tropical areas. Here insects take their heaviest toll of the world's grain supply—the United Nations Food and Agricultural Organization estimates that the grain ruined each year by insects would feed 100-million persons. Even in temperate climates the losses to insects are substantial enough ($300-million a year in the U. S.) to motivate interest in irradiation processing.

Besides being more effective and cheaper, irradiation would be safer than chemical fumigation. Most fumigants are poisonous to humans as well as to insects. With such poisons, stringent precautions must be taken and the grains must be turned and aired to remove residual poisons. In contrast, irradiation with gamma rays introduces no toxic products; effects of radiation on food quality are insignificant until doses many times those needed to kill insect eggs are reached.

As a first practical application Brownell proposes a ship-borne facility that would roam the world performing good-will services in the same manner as the "White Ship"—the hospital ship now operated under the private sponsorship of Project Hope. This scheme would tie in directly with U. S. interest



IRRADIATION SHIP anchored in port of food-scarce country would take on bulk grain from supply ships for temporary storage in aft hold (A). Grain would be packaged (B) in insect-proof bags and carried by conveyor belt past water-shielded cobalt source (C). Irradiated bags would be stored in forward hold (D) until transferred to dockside for shipment to permanent storage location. Grain in bags treated by this process would remain free from damage by insects and humidity for extended periods, and could be stacked in open storage locations with only minimal additional protection. Water shield is sea water pumped into holds when ship is docked. While ship is at sea 10^5-curie cobalt source would be stored in lead cask. Development program to put radiation processing of grain on practical basis would cost $10 million spread over period of five years

in sharing its surplus grain with underdeveloped nations.

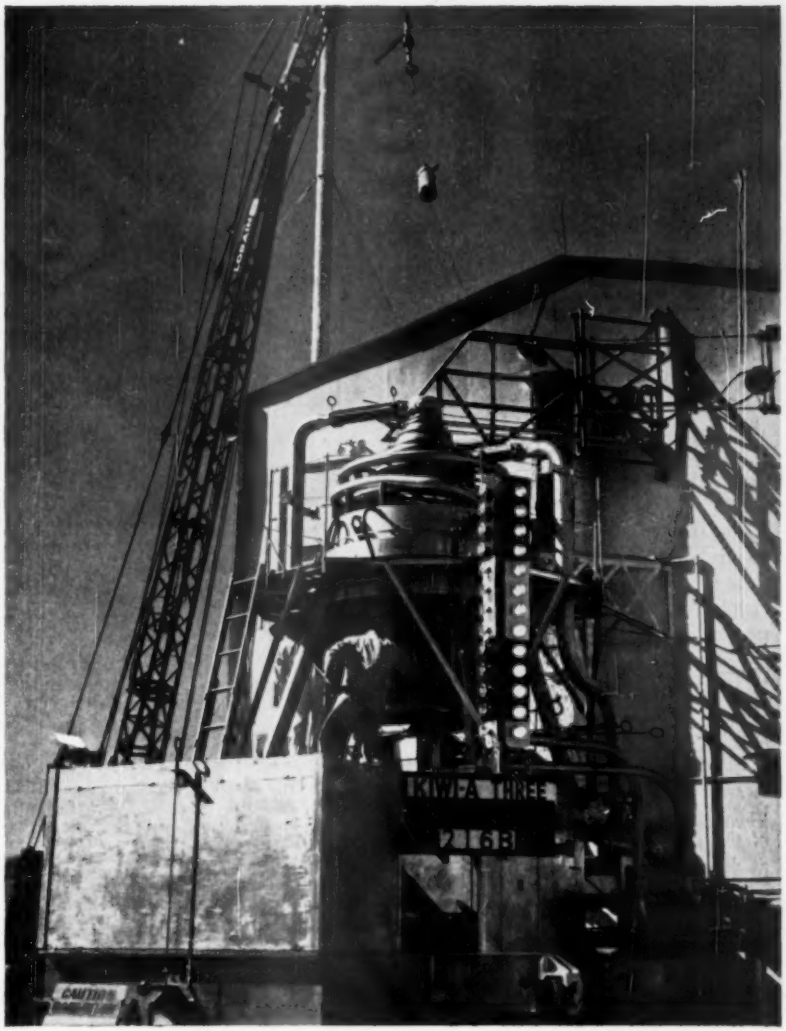
The ship (see figure) might be an old Liberty ship converted to house packaging equipment and the irradiation facility. Upon arriving at a port such as Bombay the ship would tie up at a dock. Dozens of other ships loaded with grain in bulk could pull alongside one by one and transfer their grain cargo to the irradiation ship. Once on board the grain would first be packaged in insect-proofed bags, irradiated and then transferred to dock side and sent to storage areas.

After satisfying the requirements in the Bombay area, the irradiation ship could pull up anchor for other ports such as Calcutta, Djakarta, Tokyo, and Alexandria.

Indian scientists are already working on a process to make jute bags impregnated with an insecticide that could serve as insect-proof containers. If lined with a water-proof polyethylene inner bag, these bags could be thermally sealed and would provide airtight protection from both insects and humidity. In countries with a plentiful labor supply hand-carryable bags of this kind would be a convenient and cheap way to package and handle grain. The bags could be stored for long periods of time in the open without elaborate protection—a tarpaulin cover would be enough.

In the U. S. and Europe, where labor costs justify capital investment in large storage elevators with mechanical handling equipment, these bags would not be as practical. However such countries can avail themselves of the advantages of irradiation processing by storing the bulk irradiated grain in specially built insect-proof elevators. Brownell, an expert on steel-vessel design, suggests that self-supporting cylinders of thin welded steel plate would be superior for this purpose to presently used reinforced concrete structures.

Brownell and Horne first proposed the idea of irradiating grain in tropical countries at the IAEA symposium on "Pest Control by Radiation" held in Bombay last December; the international audience of experts assembled there responded favorably to the plan. Although everyone believes that grain irradiated in this way is perfectly safe for human consumption, the Food and Drug Administration has not yet formally cleared the use of radiation on foods intended for commercial market. This would be a necessary step before irradiated grains could be offered to other countries.



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Radioactive Dating Measures Age of Industrial Products

By THOMAS C. GREGSON, SAMUEL W. WAISBROT and SAMUEL D. GEHMAN
Goodyear Tire & Rubber Company, Akron, Ohio

Radionuclide-dating techniques, which have proved very successful for dating geological formations and archeological objects (*1–5*), now offer a possible equally precise method of dating industrial products. In our new technique we introduce into an industrial commodity at the time of manufacture a selected pair of radionuclides —one with a long half-life to act as a standard and the other with a shorter half-life to be a timer. Thus the ratio of the amounts of these radionuclides at different times gives the age of the product.

Although we have tested this method theoretically and experimentally, we have so far made only preliminary experiments to demonstrate its feasibility in industry. How extensive such uses ever become depends, of course, on the safety, convenience and precision of the methods that we can develop. Our preliminary investigations, however, indicate that a broad range of dating applications exists in which our method has definite advantages over existing techniques (see box).

Our results to date indicate that we can determine ages or time intervals using ordinary end-window counting and microcurie levels with an error of $< \pm 5\%$. Because we are using exempt nuclide concentrations in our product-application studies, we are now extending our procedure to low-level radiation detection and analysis. Beta and gamma scintillation-spectrometry techniques require more skill by the operator, more sophisticated methods of sample preparation and handling and more expensive equipment. The large variety of possible applications for radionuclide timing, however, together with the accuracy of the technique, indicates that it will find many new and many extremely useful applications.

How We Time Samples

To test our theory we have made several experimental tests using beta-gamma nuclide pairs as timers and transmission techniques to measure the nuclide ratio at various times. In these experiments we prepared nuclide mixtures such as Cl^{36}/Mn^{54}, Cl^{36}/Nb^{95} and Tc^{99}/Nb^{95}, which we placed in planchets and periodically counted for activity.

In addition to these tests on planchets, we are carrying out two product-application studies to demonstrate the

Why Date Industrial Products with Radionuclides?

Many industrial products must be marked with their dates of manufacture since one must have an accurate knowledge of the age of a product to interpret properly its corrosion and weathering resistance, wearing qualities and deterioration during storage. Since conventional dating methods are often inadequate —and for some applications downright impractical—radionuclide dating will possibly provide a useful method for finding the age of a product.

Consider, for example, some of the drawbacks in conventional dating methods. Surface markings—perhaps the most versatile and widespread—are easily obliterated through weathering, abrasion or other modes of deterioration. When marked objects have been painted or buried, they must be returned to their original state before the date of manufacture can be read. In addition, the volume of mass production in many industries, especially when the items are small in size, makes dating by serial numbers cumbersome, if not completely impossible.

Besides applications to these specific examples, radionuclide dating has certain potential uses. For instance, it offers an intrinsic method of dating every particle in a package instead of just marking the outer wrapping. Thus one can always determine a reliable age for liquids and powders regardless of the number of times the bulk supply is separated or transferred from one storage vessel to another. In addition, the dating method provides a unique way of measuring the average age of material within a vessel to which periodic withdrawals and additions of material are made.

Petroleum refinery operations may also use this dating method, especially in those phases of operation that involve tank-farm storage and catalytic cracking. Cracking activity, surface area and pore volume of fluidized cracking catalysts de-activate and diminish with use (*6, 7*). At such times it is not uncommon for large cracking units to lose catalyst fines in waste stack gases at a rate of 5–10 tons/day. Consequently, to maintain an approximately constant level of catalyst activity, fresh catalyst is continuously added and spent catalyst is periodically withdrawn. By using the radionuclide dating technique, the rates at which fresh catalyst is introduced and spent catalyst is discharged could presumably be proportioned to hold the catalyst inventory at an average age and thus the activity at the desired level.

usefulness, versatility and precision of the dating method to industry. In these studies we measure the age of gasoline (dated with beta-emitting nuclide pairs and measured with low-level internal liquid-scintillation counting methods) and also the age of rubber (tagged with gamma-emitting mixtures and measured with low-level crystal scintillation techniques).

Dating planchets. During the counting procedure we pipetted into stainless-steel planchets (1.25 in. in diameter, 0.0625 in. deep) nuclides in aqueous solutions containing 30–200 nanocuries (nano- = 10^{-9}) in each aliquot. With a heat lamp the water was then evaporated. If acid was present, we neutralized the solution before evaporation with small amounts of ammonium hydroxide or sodium bicarbonate.

Through an opening in the base, we inserted the planchets into a cylindrical lead chamber (2.5 in. in diameter, 6.75 in. high) that had a vertically mounted 1.8-mg/cm² end-window G-M probe. Between the planchets and tube window we placed calibrated absorbers for transmission measurements. During the experiment we took daily background counts and standardized the system each morning by counting a sealed C^{14} reference source.

Since we did not have time to work with very long aging periods, we speeded up many of the experiments by using short-lived nuclides for timers. In this way basic mathematical and experimental principles could be established in a relatively short time. We tested mixtures of beta-, beta-gamma- and gamma-emitting nuclides in which the timer half-lives ranged from ~5 days to 3.5 yr; age periods were 0.08–4.77 times the timer half-life (see table). In addition we experimented with nuclide pairs with timer radiation softer than that of the standard and the other way around.

From these experiments we found that a standard half-life only six times that of the timer was adequate in one case so that no correction for the decay of the standard was necessary. In general, the age errors diminish with time in agreement with theory. In addition errors for comparable decay periods appear to increase with increasing nuclide ratios. We found that we should be able to determine ages with an error of ±5%.

Dating rubber samples. In addition to these planchet measurements we dated a few rubber samples with radionuclide mixtures by evaporating nuclide solutions on the surface of fully compounded, but uncured, slabs of rubber. After dispersing the radioactive residues homogeneously throughout the stock by milling it, we vulcanized sheets of the rubber. From this sheet stock we cut solid samples; we also prepared pulverized samples by grinding pieces of the sheet stock in a mortar and pestle with liquid nitrogen.

We ran into trouble when attempting to measure the ages of the dated rubber mixtures. Because of self-absorption within the sample, the nuclide ratio that one observes differs from the actual ratio; this results from a distortion of the energy spectra of the radiation coming from the surface of the rubber. These difficulties can be removed, however, by using mixtures and plot standards that appear infinitely thick to the hard emitter of the nuclide pair. We find that we will have to use low-level beta and gamma spectrometry to determine the nuclide ratios since actual product applications in the future will require minimal quantities of nuclides to meet the exempt concentrations specified by pending federal regulations.

Age Measurements with Nuclide Pairs

Nuclide pair		*Age*			
		Actual		*Measured*	
Timer	*Nuclide ratio*	*Timer half-lives*	*Days*	*Days*	*% Error*
Chlorine-36 standard					
Ca^{45}	0.44	0.12	20	18.5	−7.5
"	0.44	0.26	44	42.0	−4.6
"	0.78	0.38	63	63.8	+1.3
S^{35}	0.18	0.16	14	12.1	−13.6
"	0.20	0.42	37	37.5	+1.4
Mn^{54}	4.27	0.22	63	67.9	+7.8
P^{32}	3.75	0.42	6	7.5	+25.0
"	3.75	1.06	15	16.1	+7.3
"	1.63	0.42	6	6.2	+3.3
"	0.25	0.49	7	8.1	+15.7
"	0.25	0.91	13	13.3	+2.3
"	0.25	1.55	22	22.0	0
"	0.25	2.12	30	30.4	+1.3
"	1.94	0.56	8	7.5	−6.2
Y^{90}	0.09	0.54	1.3	1.35	+3.8
"	0.59	2.71	7.3	7.6	+4.2
Nb^{95}	0.64	1.18	41	46.2	+12.7
"	0.64	2.57	90	87.2	−3.1
Carbon-14 standard					
Bi^{210}	0.82	0.60	3	3.0	0
"	0.82	0.60	3	2.7	−10.0
"	0.82	1.93	10	9.7	−3.0
"	0.82	4.77	24	23.9	−0.4
"	—	2.00	10	10.5	+5.0
P^{32}	1.22	0.84	12	10.8	−10.0
"	1.22	1.62	23	22.8	−0.9
"	2.12	0.84	12	10.0	−16.7
"	2.12	1.62	23	21.8	−5.2
"	0.54	3.45	49	50.4	+2.9
Technetium-99 standard					
Nb^{95}	1.32	0.52	18	16.0	−11.1
"	1.32	1.69	59	59.2	+0.3
Strontium-90 standard					
Tl^{204}	0.56	0.08	103	106.3	+3.7

Theory of Technique

By using nuclide pairs in our timing method, we remove essentially all the difficulties inherent in dating with a single nuclide. Since the nuclide-pair concept eliminates any dependence on the quantity of the mixture of nuclides present, it entirely eliminates the kinds of age errors for which one normally cannot compensate when using a single decay curve. These age errors come from fluctuations in the amount of tagged material that we used and from losses in the tagged material during use or deterioration.

To determine the relative ratio of standard to timer for an age measurement, one must resolve the mixed radiation emitted by the pair into its component parts. In essence, one can differentiate between two kinds of radiation either by plotting an absorption curve and separating hard and soft components or by using pulse-height analysis to discriminate between high and low energies.

Because photons are attenuated in a purely exponential manner, resolution of gamma radiation by extrapolation is quite straightforward. Such an approach cannot be used with beta emitters because beta-particle attenuation is not exponential. One can, however, get a linear beta-transmission curve by using the Harley-Hallden method to plot against one another transmission values for a standard and an unknown nuclide through several filter thicknesses (*11*).

If one uses a pair of nuclides, a linear segment will appear only after the filters completely absorb radiation from the soft emitter (Fig. 1). The fraction of unfiltered activity contributed by the hard emitter (in this case P^{32}) can be determined easily since it is the x coordinate of the point at which the extrapolated linear portion of the curve intersects the 100% transmission ordinate of the plot standard. The fraction of soft emitter (C^{14} in Fig. 1) is the difference between the 100% transmission ordinate of the dating mixture and the point indicating the fraction of hard emitter.

The general age equation for nuclide-

pair age measurements is as follows:

$$t = 1.442\left(\frac{\tau_1\tau_2}{\tau_2 - \tau_1}\right)\log_e\left(\frac{R}{R_0}\right)$$

(t is age, τ_1 and τ_2 are half-lives of timer and standard, R_0 is initial ratio of standard to timer, R is ratio at age t.) When one uses transmission measurements, experimental data are put in place of the nuclide ratios in this equation.

Since for timing applications one needs the extrapolated transmission value instead of transmission values themselves, we modified the reference method by always using the nuclide that emits the harder radiation as our plot standard. Therefore one deals with a linear segment of known slope, and since this slope is unity, one can calculate the extrapolated transmission rather than evaluate it graphically. Thus if the maximum beta energy of the timer is harder than that of the standard and if there is no appreciable decay of the pair standard the age equation is modified to

$$t = 1.442\tau_1\log_e\left[\frac{\left(\frac{T_a^\circ}{T_a} - 1\right)}{\left(\frac{T_{0a}^\circ}{T_{0a}} - 1\right)}\right] (E_1 > E_2)$$

(T_a° is transmission of radiation from plot standard through filter thickness a, T_a is transmission from pair through same filter, T_{0a} and T_{0a}° are values at zero time, E_1 is maximum beta energy of timer, E_2 is energy standard.)

Since T_a°/T_a is the ratio of the ordinate to the abscissa in Fig. 1, only two transmission values, each at times zero and t, are needed to determine the age of an object.

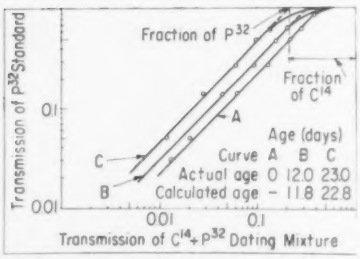

FIG. 1. AGE DETERMINATION using C^{14}/P^{32} nuclide pair. Ratio of standard (P^{32}) to timer (C^{14}) gives age of dated product

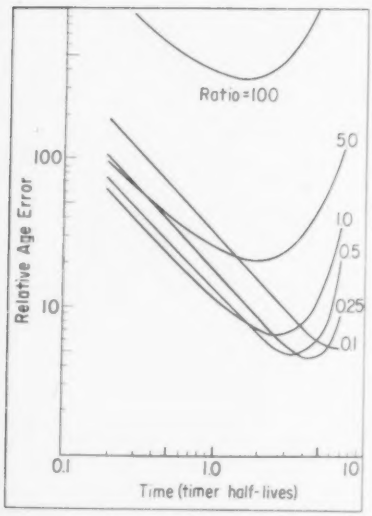

FIG. 2. NUCLIDE RATIO AFFECTS ERRORS in age measurement. From ratios on curves one sees that small initial nuclide ratios give most accurate age

Choosing Nuclide Pairs

The ultimate choice of nuclide pairs depends on the counting equipment, availability of pair species, compatibility of chemical forms with the product to be dated, length of age period and the varying concentrations that different nuclides may some day be permitted to have.

The list of nuclide pairs to choose from is large (*12*). Although one may want to use a parent-daughter combination for some applications, such a pair is not always as useful as one might hope. The number of parent-daughter pairs suitable for timing may be quite restricted because (a) the radiation from the pair may not have an energy spread large enough to determine the nuclide ratio and (b) the useful age span is limited to less than the time needed for radioactive equilibrium to occur between parent and daughter. In addition parent-daughter pairs that meet all of these specifications may then have to be rejected because of chemical considerations.

Errors in Age

Of prime concern in any age measurement is the precision one can expect. The radionuclide-dating technique has several rather obvious sources of error: uncertainty in accepted half-life, statistical fluctuations in counting rate and radioactive contaminants. The maximum errors in age calculated from

$$\frac{\Delta t}{t} = 2.884\,\frac{\tau_1}{t},\frac{\Delta R}{R}$$

diminish in magnitude as $1/t$ as aging progresses.

Figure 2 shows the dependence of age errors on the combined contributions of elapsed time and nuclide ratio (*13*). Two assumptions are necessary to get actual values for relative errors. These assumptions are first, that the activity of the pair standard equals that of the background, and second, that the ratio of the energies of timer and standard radiations is such that 80% of the timer radiation is transmitted through a filter thick enough to completely absorb radiation from the standard. These are realistic assumptions; the first is required so that permissible product-dating concentrations will not be exceeded and the second is typical of a C^{14}/P^{32} pair.

It is clearly advantageous to work with a small initial nuclide ratio of standard to timer. Note that minimal errors are encountered in time intervals of between one and five timer half-lives and that nuclide ratios of from 1.0 to 0.25 are preferable.

Age errors because of a radioactive contaminant in the dating mixture can be particularly troublesome when the contaminant radiation has an energy that makes difficult its resolution from that of either member of the pair and when its half-life is greater than that of the timer species. We have investigated age errors anticipated on the basis of contamination in the initial mixture with from 1 to 10 parts of a nonrelated species per 100 parts timer species as well as those induced by the self-generation of a daughter species. These errors in age can be computed from

$$\frac{\Delta t}{t} = -1.442\,\frac{\tau_1}{t}\,r_o e^{-0.693t(j-1)/\tau_1} \quad (1)$$

when $\quad r_o e^{-0.693t(j-1)/\tau_1} \leq \frac{1}{10}$

(j is half-life ratio of timer to nonrelated contaminant species, r is concentration ratio of contaminant to timer.) If r_0 times the exponential term is greater than one tenth, Eq. 1 exaggerates the magnitude of the errors. The time

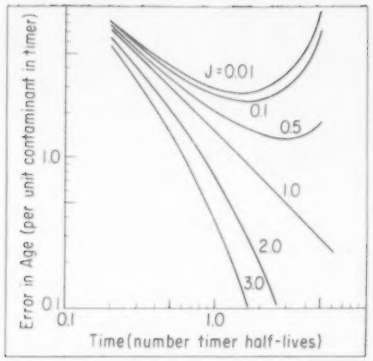

FIG. 3. CONTAMINANT AFFECTS ERRORS in age measurement. Curves, computed from Eq. 1 in text, show time dependence of age errors from contamination. J is half-life ratio of timer to nonrelated contaminant species

dependence of this error, computed from the equation is shown in Fig. 3. Generally speaking, the error contribution arising from daughter growth is more complex and even more serious than that from a nonrelated species.

From these observations we concluded that errors in age will be minimized when (a) measurements are limited to a time interval of 1–5 timer half-lives, (b) the initial concentration of standard species in the dating mixture is smaller than that of the timer species (ratios of 0.1–1.0 are preferable) and (c) if possible, counting determinations are programed to eliminate statistical errors. Moreover, pair species must be selected so that the initial presence or the generation during use of other radioactive species is eliminated.

* * *

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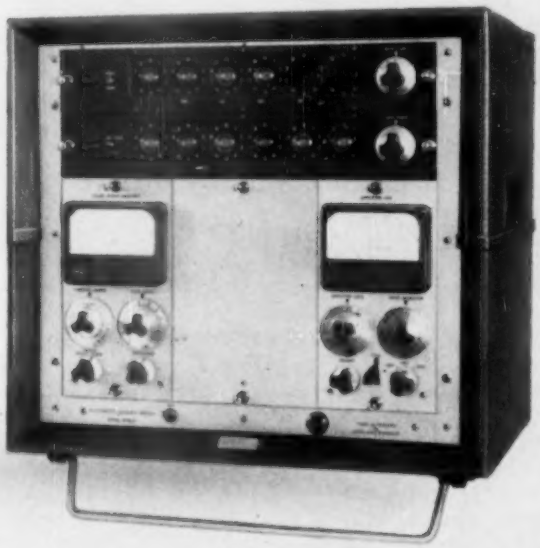

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NUCLEAR BOOKSHELF

Activation Analysis Handbook

By R. C. KOCH (Academic Press, New York, 1960, $8, x + 219 pages)

Reviewed by VINCENT P. GUINN, Shell Development Co., Emeryville, Calif.

This book is essentially a tabulation, not a text; of its 219 pages, only 19 are devoted to explanatory material. The purpose of the book is best expressed by its author on page 1. He writes:

> *Its purpose is to present a tabulation of the published data pertinent to activation analysis. In particular, this tabulation includes for each element: (1) data for activation analyses utilizing thermal and fast neutrons, charged particles, and photons; (2) nuclear data for these reactions; (3) nuclear data for other reactions potentially useful for activation analysis; (4) nuclear data for possible interfering reactions; (5) evaluations of these reactions; (6) sensitivities for the more important neutron and charged particle reactions for each element; and (7) complete bibliographical referencing for all of the data presented.*

This thorough tabulation contains 166 pages and covers essentially all of the literature (to September, 1959) on nuclear reactions induced in stable isotopes (and long-lived natural radioisotopes) by thermal and fast neutrons, protons, deuterons, alpha particles and photons of moderate energy. In addition, the 13 pages of bibliography contain 570 references to the literature of activation analysis, nuclear reactions, cross sections and nuclear-decay data.

From the standpoint of a person actively engaged in activation analysis, I find this book to be a thorough, well-organized and useful tabulation of data, as well as an excellent guide to the literature of the subject.

The field of activation analysis is one that should grow by leaps and bounds during the next few years. With the recent advent of low-cost ($20,000) accelerators and highly-versatile multichannel pulse-height analyzers ($10,000–$20,000), many additional laboratories can and will begin to make use of activation analysis. The recent availability of relatively low-cost ($150,000), but high-performance, nuclear reactors will also spur on the use of activation analysis in many fields of science and industry. In our laboratory, for example, a system of purely instrumental thermal-neutron activation analysis using a 3-Mev Van-de-Graaff electron accelerator and a multichannel analyzer has been in very satisfactory routine operation, 40 hours per week, for over two years. Recently, we augmented this program with a system of activation analysis using 14-Mev neutrons produced by a low-cost 150-kev Cockcroft-Walton deuteron accelerator. This system, too, is proving very useful.

As more and more laboratories discover the possibilities of activation analysis in their particular fields, and find that the cost is no longer prohibitive, this method will grow rapidly. The "Activation Analysis Handbook" should prove to be a helpful tabulation of data and guide to literature for the many new entrants into the field of activation analysis, as well as for those already engaged in this work.

Digital Computers and Nuclear Reactor Calculations

By WARD C. SANGREN (John Wiley & Sons, New York, 1960, $8.50, xi + 208 pages)

This book is an excellent tutorial review of the use of high-speed digital computers in the reactor-design field. The first four chapters, which are general enough to serve as an introduction to high-speed calculations in any field of engineering or physical science, orient the beginner briefly with the problems of reactor design, the nature of digital computers and, in more detail, with the steps involved in computerizing a technical calculation. According to the author there are three basic steps in this operation: (1) converting the physical problem to a mathematical one; (2) putting the mathematical problem into a form amenable to numerical analysis; and (3) programming the numerical analysis problem on the computing machine.

Chapter 5 gathers together what has been said so far to carry the reader through the digital solution of a well-chosen practical reactor calculation concerning fission-product poisoning. The remaining three chapters are a survey of the more prominent reactor calculations presently carried out on digital computers. In these chapters, the emphasis is on establishing mathematical models, with some discussion of numerical analysis and relatively little on the mechanics of programming. The author makes only brief reference to typical existing codes that solve the problems discussed. While it would be impractical in this book to provide a definitive survey of existing codes, the author could profitably have dwelled at greater length with a few of these codes to give the neophyte a moer quantitative feeling for their capabilities and the time and effort required to develop and operate them. As it is, the reader is left with little appreciation of the vast difference in complexity between, say, a one dimensional 2-region, 2-group code and the three dimensional multiregion, multigroup lifetime calculations now under development.

Although the author may not have placed the profusion of existing reactor codes into as clear a perspective as many readers would want, he has undoubtedly succeeded in the more significant task of elucidating the principles and techniques basic to the work of creating these codes. —HLD

Dynamic America

Edited by JOHN NIVEN, COURTLANDT CANBY and VERNON WELSH (General Dynamics Corp. and Doubleday & Co., Inc., New York, 1960, $20, 426 pages)

There have been company histories written before; there have been nostalgic albums dedicated to reminiscing about the good old times; there have been fancy editions concentrating on their graphic-arts content and aimed at making an impression on bibliophiles. Now comes a book that not only combines all three but sets a new high standard in each. And it is the history of a leading company in the atomic field—a company five of whose eight divisions are deeply involved in nuclear activities.

"Dynamic America" is subtitled "A history of General Dynamics Corporation and its predecessor companies." It is of course much more. It is an industrial history of the U. S. since 1880—selective rather than comprehensive, to be sure, but it is surprising how broad is the canvas covered in just tracing the areas in which General Dynamics' constituent companies have operated.

But in just admiring the lavish beauty of the book's color illustrations, design and printing, one can easily lose sight of the fact that the text is well-planned, excitingly written history that commands attention. If the book's

over-all space allotment is perhaps a mite unfair to General Dynamics' Liquid Carbonic and Materials Service divisions to favor the more glamorous stories of the development of the airplane and the submarine, this in no way lessens its interest for the general reader. —JK

BOOKS RECEIVED

Kernenergie-Technik, by H. Engel and K. O. Thielheim (Verlag Moderne Industrie, München, 1960, DM 36, 299 pages). For readers of German, this edition is a fine introduction to the physics and engineering of reactors. Aimed primarily at engineers, it is written at a level useful for college students as well as scientists in other disciplines. The book's three parts cover: physical and engineering foundations, particular reactor types, and economic considerations, with a final chapter on fusion. Text, illustrations and bibliography show familiarity with French and British as well as German sources and nuclear facilities, but the overwhelming majority of the book's discussion is based on American work. —JK

Eléments de Physique Nucléaire, by Daniel Blanc and Georges Ambrosino (Masson & Cie., Paris, 1960, 30 NF, 238 pages). In a preface of this textbook in French on the basic principles of nuclear physics, Henri Baissas, director of the French AEC's Fontenary-aux-Roses nuclear research center, points out that "paradoxically, in spite of its Becquerels, Curies, Perrins, Joliots, France has practically no treatise on nuclear physics, other than translations of foreign works." This book fills the gap. Intended primarily for university students, it is also especially useful, Baissas points out, to engineers in the field who have not had formal academic training in nuclear physics, and to people in industry using radionuclides as tracers. The book concentrates on experimental results, deemphasizing the theoretical deductions; it gives the basic mathematics and formulas necessary for practical use in engineering; an appendix furnishes useful constants and conversion factors. —JK

Power Reactor Technology, edited by James K. Pickard, Frederick H. Warren, William W. Lowe and Stuart McLain (D. Van Nostrand Co., Inc., Princeton, N. J., 1961, $11.25, ix + 417 pages). This new addition to the "Second Geneva Series on the Peaceful Uses of Atomic Energy" contains edited versions of some of the important reactor papers presented at Geneva. Since the conference stressed reactor-design factors rather than operating results, this book is a convenient reference to the initial design approaches used in the leading nuclear power plants throughout the world.

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Div. of Nuclear Corp. of	*l*-asparagine-C^{14}	1–5	950
America	dihydroxyacetone-1-C^{14}	1–5	800
P. O. Box 688	dihydroxyacetone-2-C^{14}	1–5	900
Burbank, Calif.	versene-C^{14}, ethylene diamine	1–5	600
	alkylbenzenesulfonate-S^{35}	1–2	395
Merck Sharp & Dohme	benzoyl-D_5 chloride (99% D)		175/5 gm
560 De Courcelle St.	malonic acid-1, 3-C^{14}	1.3	300
Montreal, Canada	malonic acid-2-C^{14}	1	320
	ethylene-1-D (98% D)		150/liter
	chloroacetamide-D_4 (98% D)		375/5 gm
New England Nuclear Corp	*l*-methionine-S^{35}	1–5	75
575 Albany St.	*dl*-tyrosine-3-C^{14}	1	550
Boston 18, Mass.	*l*-proline-3, 4-H^3	50	100
			300/5 mc
	dl-mevalonic-5-H^3 acid (DBED salt)	25	225/5 mc
	5,5-diphenylhydantoin-4-C^{14}	1–5	850
Nuclear Research Chemicals,	acrylonitrile-1-C^{14}	1	800
Inc.	isoprene-1-C^{14}	1	1,200
P. O. Box 6458	styrene-7-C^{14}	1–5	650
Orlando, Fla.	toluene-1-C^{14} (ring)	2–10	450
	trypan blue-C^{14}		2,000
Radiochemical Centre	*dl*-tryptophan (benzene ring-		
Amersham	U-C^{14}	3*	
Buckinghamshire, England	*dl*-ethionine-T (G)	50*	
	deoxyuridine (nominally 5,6-T)	400*	
	lithium borohydride-T	100*	
	tryptamine-T (G)	25*	
Twentieth Century Electronics Ltd.	boron-11 (isotope enrichment 98%)		
Croydon, Surrey, England			
U. S. Nuclear Corp.	galactose randomly labeled	2–7	
P. O. Box 208	glyceric acid-3-Cl_4	2–4	
Burbank, Calif.	phenobarbital-2-Cl_4	2–4	
	pentaborane-T	7–10	
	diethyl ketone-C^{13}	60%	
Volk Radiochemical Co.	acetone-1,3-T	350	145/20 mc
5412 N. Clark St.	*dl*-alanine-2,3-T	150	145/5 mc
Chicago 40, Ill.	glycine-2-T	150	145/5 mc
	indolylacetic-T acid	100	145/5 mc
	sodium borohydride-T	50	145/10 mc

* Cost on request.

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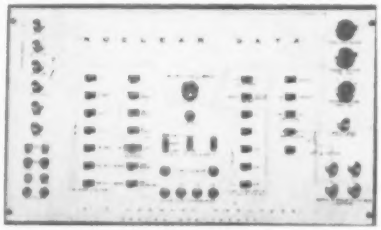

512-Channel Analyzer

Model ND 120 rack-mounted analyzer (above) has 10^6 count capacity and accessible circuitry. The analyzer is based on Nuclear Data's 256-channel analyzer, but has various circuit improvements.—Nuclear Data Inc., P. O. Box 1464, Madison, Wis.

Elk River's New Stainless-Steel Clad End Closure

END CLOSURE FOR REACTOR weighs 13½ tons; inside dia. of head is 84 in.—Lukens Steel Co., Coatesville, Pa.

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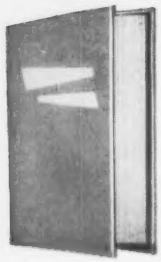

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Products and Materials

Department starts on page 96

Radioisotope Training Kit for Students' Experiments

RADIOISOTOPE EXPERIMENTS on the undergraduate level can now be done with this training set. The kit contains a scaler, timer, G-M tube and mount, teacher's and student's manuals, two sample-preparation sets, a solid radioactive source set and radioactive reagents.—Nuclear Chicago Corp., 359 Howard Ave., Des Plaines, Ill.

Portable Survey Meter

Portable Model 489 Thyac II survey meter, complete with transistors, offers interchangeable G-M or scintillation probes for detecting and measuring radiation. The 4-lb meter has sensitivity ranges of 800, 8,000 and 80,000 cpm. Four D-flashlight batteries supply power.—Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

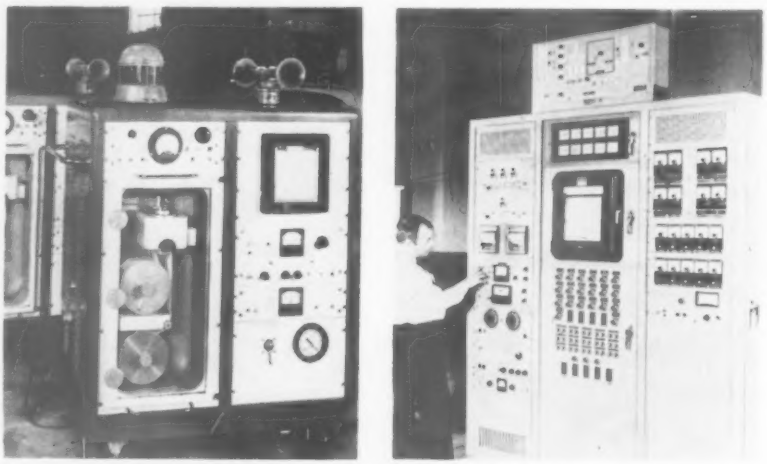
New Nixie indicator tubes. New series of tubes have flattened tube faces and cutaway anodes so that the cathode numerals can be placed higher. These changes have increased the viewing angle from 90 to 160 deg.—Burroughs Corp., Plainfield, N. J.

Charge-Sensitive Preamplifier

Because of its charge-sensitive feedback configuration, the Model 100A Preamplifier is ideal for use with semiconductor radiation detectors. The charge sensitivity varies $<10\%$ over the detector capacity range of 0-1,000 $\mu\mu$f; noise is equivalent to 600 electrons rms with a 10-$\mu\mu$f detector and 1-μsec shaping networks. Risetime is <0.1 μsec with detector capacities of 300 $\mu\mu$f.—Tennelec Instrument Co., P. O. Box 964, Oak Ridge, Tenn.

14,000-lb aluminum ingot. Four of these giant ingots (above), the largest ever poured, will be used in the Rover Program to develop a nuclear rocket.—Kaiser Aluminum, 300 Lakeside Drive, Oakland 12, Calif.

Radiation Monitoring for Hallam's 75-Mw Nuclear Power Plant



RADIATION MONITORING SYSTEM has central control unit (right) that records immediately radiation level in air from remote monitoring units (left) placed at strategic locations throughout plant.—Victoreen Instrument Co., 5806 Hough Ave., Cleveland, Ohio.

Neutron detection foils (above) offer a simple method of absolute neutron-flux calibration with ±3.2% accuracy. Gold, indium, cobalt, plutonium, uranium, sulfur, sulfur-graphite and aluminum foils are available with cadmium covers, boron shields, sulfur-foil containers and Cs^{137} as a calibrated source. —Aerojet-General Nucleonics, P. O. Box 77, San Ramon, Calif.

Pocket-size dose-rate alarm. Compact FIDO has an adjustable trigger level that sets off a siren alarm audible 100 yards away when it records dangerous radiation levels. The solid-state device responds to dose-rate ranges of 50–10^7 mr/hr.—Controls for Radiation, Inc., 130 Alewife Brook Parkway, Cambridge 40, Mass.

Do-it-yourself periscope. With Kollmorgen building-block components, you can assemble your own precision periscope for hot-cell or under-water viewing. Periscopes can be built with any length or configuration; 1½-, 3-, 6- or 12-power telescopes are available. —Kollmorgen Corp., Northampton, Mass.

Portable detector and battery amplifier. DT-10, a transistor, multiprobe detector, allows a G-M tube and a scintillation probe to be connected simultaneously. The circuit operates from a rechargable battery. A plug on the rear panel connects the charger directly to a 127-volt or 220-volt a-c power supply. Ratemeter has 3 ranges: 0–10, 0–100 and 1–2,000 cps; scaler has single range of 0–500 counts.

Logarithmic d-c amplifier covers 6 decades with a drift $<\frac{1}{10}$ decade from −40 to +70° C. Radiation doses of 10^{-3}–10^3 r/hr can be measured—Intertechnique, 52 Wall St., New York N. Y.

Portable pulse-height analyzer. Model 404, a 400-channel pulse-height analyzer, weighs 30 lb, contains transistors and accommodates four detectors at once. Each input has its own amplifier and gain control; data are stored in a magnetic core memory sys-

(Continued on page 100)

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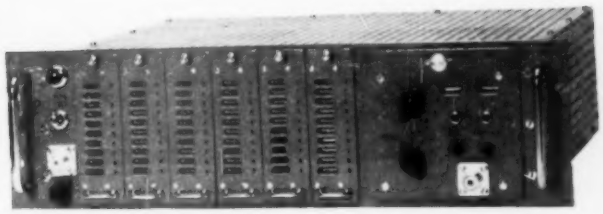
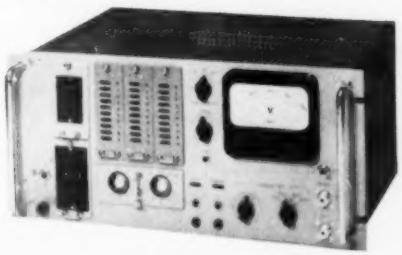


MODEL ECH 6 T

- 6 interchangeable decades
- Scaler resolution: 1 μs or 0.1 μs
- Storage: 10^6 counts
- Optional mechanical register
- Stop at preset count
- Input polarity: negative or positive by a switch
- A gate is provided to start or stop
- Reset possible by external pulse



MODEL ECG 3 T

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tem.—Technical Measurement Corp., 441 Washington Ave., North Haven, Conn.

Single hand monitor. Portable SHM1 (above) has 5-sec counting time, 13% alpha and 30% beta efficiency. The hand counters are scintillators and dual phosphors.—E.M.I. Electronics Ltd., Hayes, Middlesex, England.

LITERATURE AVAILABLE

Revised Price List. 4 pp.; Technical Associates, 140 W. Providencia Ave., Burbank, Calif.

Automatic 200 Sample Changer. 2 pp.; Technical Associates, 140 W. Providencia Ave., Burbank, Calif.

Safety & Special Enclosures. 31 pp.; Kewaunee Scientific Equipment, Adrian, Mich.

Counting Instruments & Accessories. 11 pp.; ATOMasters-Buntaine Corp., 111 W. Jewel Ave., St. Louis 22, Mo.

Portable Transistorized Count Rate Meter & Area Monitor. 2 pp.; Universal Transistor Products Corp., 36 Sylvester St., Westbury, L. I., N. Y.

The Single or Multi-Station γ Detection System. 4 pp.; NMC, Indianapolis, Indiana

Scintillation Grade Fluors; Plastic Scintillators. 4 pp.; Pilot Chemicals, Inc., 36 Pleasant St., Watertown 72, Mass.

Services in Research. 68 pp.; Isotopes, Inc., 123 Woodland Ave., Westwood, N. J.

Nuclear Health Short Form Catalogue. 4 pp.; EMI Electronics Ltd., Instrument Div., Hayes, Middlesex, England

NCA Film Badge Service. 4 pp.; Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.

R. F. Ion Source. 2 pp.; Oak Ridge Technical Enterprises Corp., P. O. Box 524, Oak Ridge, Tenn.

Labeled Nucleosides. 2 pp.; New England Nuclear Corp., 575 Albany St., Boston 18, Mass.

Cobalt 60 Radiation. 8 pp.; Atomic Energy of Canada Ltd., P. O. Box 93, Ottawa, Canada

C^{14}-Labeled Radiochemicals. 4 pp.; Research Specialties Co., 200 So. Garrard Blvd., Richmond, Calif.

Stable Isotopes of Oxygen. 8 pp.; Weizmann Institute of Science, Isotope Dept., Rehovoth, Israel

Nuclear Activities. 28 pp.; Combustion Engineering, Inc., Windsor, Conn.

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INDUSTRY NOTES

● **Elgin Laboratories,** Waterford, Pa., will supply 1,000 personal radiation monitors at $51.23 each to Oak Ridge National Laboratory. The fountain-pen-size monitors, developed at ORNL, indicate the presence of radiation by a flashing light and a chirping noise.

● **The Atlantic Research Corp.,** Alexandria, Va., has purchased about 15% (30,000 shares) of Nuclear Science and Engineering Corp., Pittsburgh. Atlantic Research's participation in the nuclear-engineering field has included projects for AEC and the Air Force. The firm's Nuclear Engineering div. is now building its own hot laboratory.

● The Air Force has granted the **Marquardt Corp.** a $4-million renewal of its research contract to develop a nuclear ramjet engine, Project Pluto. Marquardt and Lawrence Radiation Lab. have been conducting research on Pluto under Wright Air Development div.-Air Force contracts since 1956.

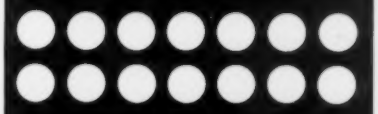
NEW BUSINESS: An $80,000 research and development contract from the Goddard Space Flight Center, Green Belt, Md., for study of means of detecting atomic gases in outer space is one of four contracts recently awarded to **Tracerlab.** The other three: $20,000 from the Wright Air Development div. of Wright Patterson Air Force Base for developing instrumentation to detect toxic gases at exotic-fuel fabrication sites; $334,384 from the Navy's Bureau of Ships for manufacture of 58 air-particle monitors for nuclear-powered vessels; an AEC Office of Isotopes Development contract for $46,000 to investigate methods of producing scintillating ion-exchange resins to detect minute quantities of radiation. . . . A recipient of three new contracts is the newly reorganized Instrument and Control div. of **Nuclear Corporation of America.** Under one, with the Komline-Sanderson Engineering Co., Nucor will supply radiation gages to measure concentration of solids in sludge. The other two, both from the Navy, are for fast-neutron detection and measurement instruments and for classified research and development. . . . NASA's Marshall Space Flight Center, Huntsville, Ala., has awarded an $86,500 ion-beam study contract to **Space Technology Laboratories,** subsidiary of Thompson Ramo Wooldridge. . . . Panellit div., **Information Systems, Inc.** has received a $550,000 contract from General Electric to furnish pressure gages for Hanford Atomic Products Operation, Richland, Wash. **High Voltage Engineering Corp.,** Burlington, Mass., has sold 5.5-Mev positive-ion accelerators, valued at more than $2-million, to four nuclear research centers: Japan Atomic Energy Research Institute; University of Padua (Italy); University of Frankfurt (Germany); and Laval Univ. (Canada).

ACQUISITIONS: The merger of **Nuclear-Chicago Corp.** and **Texas Nuclear Corp.,** Austin, Tex., (NU, Dec. '60, 34) was consummated last month. Texas Nuclear, operating as a wholly-owned subsidiary of Nuclear-Chicago, will maintain existing facilities and personnel and continue to manufacture neutron generators. . . . **Kermac Nuclear Fuels Corp.,** subsidiary of Kerr-McGee Oil Industries, has acquired all capital stock of Lakeview Mining Co. and Gunnison Mining Co. both of which are under contract to AEC to convert uranium-bearing ores into uranium oxide (U_3O_8).

FINANCIAL: The largest net profit in its history, $204,413 in calendar 1960, was announced by **Tracerlab, Inc.** at its annual meeting in April. At the same time, the stockholders voted to increase the authorized stock by 30,000 shares. . . . **Victoreen Instrument Co.,** Cleveland, has filed a statement with SEC seeking registration of 350,000 additional shares of common stock to be offered at the market price. The proceeds will be used for new equipment and facilities, and modernization of two subsidiaries—John E. Fast & Co. and Kolus Corp. . . . **Royal Industries, Inc.,** Los Angeles, showed a 1960 net income of $467,583 or 42¢/share.

EXPANSION: An electrical propulsion laboratory has been completed at the Canoga Park (Calif.) Research Center of the **Rocketdyne div.,** North American Aviation, Inc. The laboratory, containing six space-simulating vacuum tanks, provides research and development facilities for experimental studies based on nuclear and solar power sources. . . . **Nuclear-Chicago** is planning to enlarge its Des Plaines, Ill. facilities to 96,000 ft² from 41,000 ft² beginning about May 1.

Pu:Be



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NUCLEAR CALENDAR

International Atomic Energy Agency

June 5–9—Symposium on Radiation Effects on Nerves and the Central Nervous System, Vienna.

June 13–16—Symposium on Whole Body Counting, Vienna.

August 3–11—Seminar on Physics of Fast and Intermediate Reactors, Vienna. On all IAEA meetings, contact IAEA, 11 Kärntnerring, Vienna 1, Austria.

June 4–8—American Nuclear Society Annual Meeting, Pittsburgh, Pa. (*Penn-Sheraton*). Sponsor: ANS. Contact: Octave J. DuTemple, ANS, 86 East Randolph St., Chicago 1, Ill.

June 11–16—Health Physics Society Meeting and Exhibition, Las Vegas, Nev. See program, page 64A.

June 12–15—International Conference on Physics of Electronic and Atomic Collisions, sponsored jointly by New York University and University of Colorado; University of Colorado, Boulder, Colo. Contact: B. Bederson, Physics Dept., NYU, New York 53, N. Y.

June 12–Sept. 1—Gordon Conferences in the summer at Colby Junior College, New London, N. H.; New Hampton School, New Hampton, N. H.; Kimball Union Academy, Meriden, N. H.; Tilton School, Tilton, N. H. For details and dates, contact: W. George Parks, Director, Univ. of Rhode Island, Kingston, Rhode Island.

June 13–16—National Joint Meeting of the Institute of Aerospace Sciences and the American Rocket Society, Los Angeles (*Ambassador*). Contact: J. W. Wechsler, 7660 Beverly Blvd., Los Angeles 36, Calif.

June 14–17—Eighth Annual Meeting of the Society of Nuclear Medicine, Pittsburgh, Pa. (*Penn Sheraton*). Contact: Samuel M. Turiel, SNM, 430 No. Michigan Ave., Chicago 11, Ill.

June 22–24—American Physical Society meeting, Mexico City. Contact: K. K. Darrow, APS, 538 W. 120 St., New York 27, N. Y.

June 27–28—Symposium on Radiation Effects on Refractory Fuel Compounds, Atlantic City, N. J. (*Chalfonte-Hadden Hall*). Sponsor: Battelle Memorial Institute. Contact: American Society for Testing Materials, 1961 Race St., Philadelphia, Penna.

NEWSMAKERS

Charles E. Crompton will head the Martin Co.'s newly-formed Nuclear Chemistry department to integrate all Martin nuclear-chemistry activities at both Baltimore and Quehanna, Pa. plants. The new department will provide technical support for other departments engaged in producing auxiliary power systems—such as the SNAP (Systems for Nuclear Auxiliary Power) Program, reactor power plants and reactor fuel elements. Crompton has been associated with the nuclear energy field since he served on the Manhattan Project at Oak Ridge during World War II.

Crompton

Leonard C. Koke has been named manager of the Vallecitos Experimental Superheat Reactor (VESR) for the General Electric Atomic Power Equipment Department. The $8-million VESR prototype, being built by GE in conjunction with the ESADA (Empire State Atomic Development Associates) group, is scheduled for a construction start next month and completion in mid-1962.

Koke

Edward J. Brunenkant, Jr., has been appointed Director of the Office of Technical Information of the AEC. Brunenkant, who had been acting director of the Information Office since August, 1960, has been on the Commission staff since May, 1953, first as Industrial Information Officer in the Division of Information Services, then as Chief of the Industrial Information Branch. Also at the AEC, **Milton Klein,** formerly Assistant Manager for Technical Operations at the Chicago Operations Office (COO), has been appointed Deputy Director of the AEC-NASA office attached to the AEC Division of Reactor Development. **Thomas A. Nemzek** will succeed Klein in Chicago. Other AEC changes include: **Claude A. Pursel,** appointed Director of the Reactor Engineering div., **John P. Jewett,** named Assistant Manager for Administration—both at COO, and **John X. Combo** to succeed **Paul B. Martin** as Chief Counsel at the Grand Junction (Colo.) Operations Office.

Harold Etherington has been appointed general manager of the Allis Chalmers Atomic Energy div., succeeding Roy M. Casper who was recently named general manager of the A-C Power Equipment Division. **Henry C. Nickel,** previously assistant manager of the nuclear power dept., will succeed Etherington in the A-C Washington office.

Edward F. Weisner of Atomics International is project engineer for preliminary design of the 150-Mw organic-moderated and -cooled reactor for Baden Wurttemberg Nuclear Power Plant Planning Association of Germany.

John R. Stehn has been named director of the Neutron Cross Section Compilation Group at Brookhaven National Lab. The Compilation Group, part of BNL's Sigma Center, collects available information on neutron cross sections and associated nuclear properties of all materials, maintains files of its findings, and publishes compilations of the information. The Reactor Cross Section Evaluation Group, also part of the recently expanded Sigma Center, has full access to the files of the Compilation Group and uses the information to aid in supplying cross-section information for reactor applications. Stehn was formerly a theoretical physicist on the staff of General Electric's Knolls Atomic Power Laboratory where he edited the GE Chart of the Nuclides.

Stehn

Homer S. Myers, one of the founders of Tracerlab, has been elected Executive Vice President of that company. Myers, previously Vice President and General Manager of Marketing, will retain his marketing responsibilities. At the same time, **Abel DeHaan, Jr.** was elected a Vice President. He will continue as General Manager of Tracerlab's Reactor Monitoring Center in Richmond, Calif.

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Newsmakers

Department starts on page 105

Louis B. Werner, formerly AEC Scientific Representative in the U. K. and Ireland, has joined Hazleton-Nuclear Science Corp. as a vice president. The newly created position is part of a planned expansion that will combine advanced radioactive technique with the present analytical chemistry programs.

The International Atomic Energy Agency has named directors to four of its divisions. The new directors, who assumed their duties in April, are: **Dennis Wiffen Pearce** (U. S.), div. of Health, Safety, and Waste Disposal; **Dr. Dragoslav Popovic** (Yugoslavia), Safeguards div.; **Carlos Sanchez del Rio** (Spain), Reactor div.; and **Cestmir Simane** (Czechoslovakia), div. of Technical Supplies.

W. Howard Arnold has joined the staff of Nuclear Utility Services, Inc. as Director of Nuclear Fuel Management. He will be in charge of reactor refueling schemes as well as general consulting in the reactor physics area. Previously, as manager of the Westinghouse Atomic Power div. reactor physics design section, Arnold was responsible for the nuclear design of the SELNI, CVNPR, Saxton, SENA, and Southern California Edison reactors. NUS has also appointed to its technical staff **Donald L. Couchman** who had previously been project officer for the Shippingport Atomic Power Station in the AEC Naval Reactors Branch.

Arnold

Elda E. Anderson, recently named chairman of the American Board of Health Physics, died April 17 in Oak Ridge, Tenn. Miss Anderson served as president of the International Health Physics Society last year and conducted the first three International Courses in Health Physics in 1955, 1957, and 1958.

Anderson

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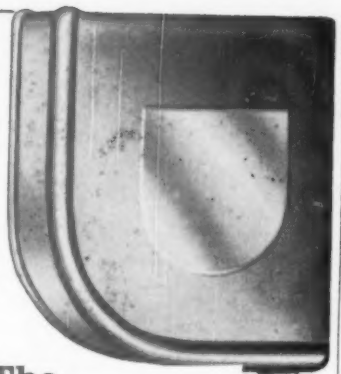

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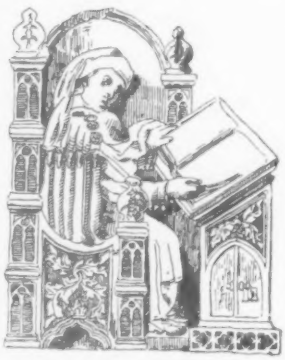

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In our exultation over Commander Shepard's successful vault into space, we of the free world tried hard to ignore the fact that as much as another year might go by before an American astronaut equals Major Gagarin's historic accomplishment three weeks earlier. But we can afford no illusions about the realistic state of affairs. The USSR now leads in total point score for space spectaculars and will continue to lead for many years, even though we plan substantial increases in our man-in-space efforts.

As a balm for our pride during these lean years President Kennedy has directed the National Space Council to single out some other area in space in which we can mount a crash program to surpass the Soviets in the not-too-distant future. But what can we hope to do that will compete for attention with the even more breathtaking cosmic acrobatics that are certain to follow this spring's initial performances? We can think of only one thing that would measure up—*a satellite system providing worldwide television and radio coverage.*

Technically we could accomplish this by placing three SNAP-8 reactors equal distances apart in a 24-hour orbit. These stations would have power enough to relay as many as ten television channels at signal strengths that could be picked up by home-size receiving antennas at any point on the face of the earth. (This system would be distinct from the one proposed by American Telephone & Telegraph for telephone communication, which would require elaborate receiving stations.)

Should we succeed in an all-out program to put this system into orbit in, say, the spring of 1964, we could then boast that

- We were first to put a satellite into the 24-hour orbit (the orbit in which a satellite hovers over a fixed point on the earth)
- We were first to use nuclear power and electrical propulsion for a space mission (after being lifted into a 300-mile-high orbit by an Atlas-Centaur, the nuclear-powered SNAP-8 system would raise itself with electrical propulsion to the 24-hour orbit at 22,300 miles)
- Most important of all, we were first to apply the new space technology to a project of direct and lasting benefit to all the peoples of the world.

From the practical standpoints of cost and chances of success, the SNAP-8 project has many arguments in its favor: We are already well along with this project. Information on SNAP-8 is almost entirely unclassified. The basic technology of the reactor has been demonstrated by the AEC through the successful long-term operation of the SNAP-2 prototype. The SNAP-8 reactor design represents a modest extrapolation of this experimental data. NASA already has a complete schedule laid out for development and testing of both the electrical propulsion unit and the SNAP-8 power supply. This schedule calls for an initial nuclear flight test in March of 1965 with operational status following at some later time depending on the first mission (as yet unassigned by NASA). To have the complete propulsion and power-supply system ready at a much earlier date we need only accelerate the existing development schedule and assign the specific mission that we propose here. In concentrating on SNAP-8 as the key element of a worldwide communication system we would be exploiting one of the areas in space technology in which we probably now hold a lead over the Russians—compact nuclear-power sources.

Last of all, the money needed to support an all-out effort on this project could be measured in millions rather than the billions we associate with man-in-space missions. This is one space spectacular that we can pay for out of petty cash!

The obvious objections to any one nation setting up a world-wide system of this kind (questions of sovereignty in stationing a transmitter satellite—especially a nuclear-powered one—over foreign territory) could be swept aside by the offer on the part of the United States to place the whole system, when the means for creating it have been developed, at the complete disposal of the United Nations. This gesture would back up in a dramatic way President Kennedy's expressed desire that nations cooperate in bringing the benefits of the space age to the whole of mankind.

Beyond its immediate value as a reply to Soviet boasts in the propaganda arena, the SNAP-8 communication system holds out the promise of something far more important—the prospect of an ultimate solution to our problems through an informed and educated world citizenry.

To design vehicles for the Space Age, it is necessary to know how materials will behave in cryogenic environments. We're now working under contract with the NASA to determine the properties of materials subjected to neutron and gamma radiations in extremely low temperatures—even below that of liquid hydrogen. Our nuclear-cryogenics capability includes design, fabrication, installation, and operation of in-pile dynamic test loops, refrigeration systems, instrumentation, and remote handling facilities. Address: Lockheed Nuclear Products, 1500 Northside Dr., N.W., Atlanta 18, Georgia.

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New Instrument Measures Beta, Low-Energy X-Rays

CLEVELAND — A portable, vibrating reed, low-energy survey meter of extreme sensitivity for detection and measurement of beta and gamma radiation over a broad energy range was shown here today by the Victoreen Instrument Company.

According to a company spokesman, the new Victoreen Model 440 Low Energy Survey Meter brings greater safety to gamma ray surveys because it includes the often dangerous scatter components in the measurement.

Additional new applications pointed out for particular attention were X-ray crystal spectrometers, dental X-rays, radar sites, etc.

Victoreen, the pioneer designer and producer of radiation detection and measurement instruments, states the Model 440 has an accuracy of ±10% with gamma energy dependence of ±15% from 6.5 Kev to 1.2 Mev.

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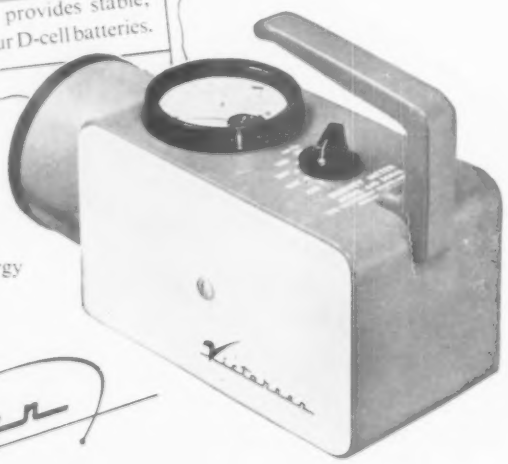
Instrum...

AEC Sets New Lower Radioactivity Limits

WASHINGTON — The Atomic Energy Commission has sharply cut permissible radiation exposure standards, according to a statement issued here.

The new lower limits — the first change in the regulations in 3 years — will reduce lifetime accumulated dose to one-third of the previously permitted amount. Affected by the order are workers in nuclear installations, X-ray and radar



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